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13. ABSTRACT *(Maximum 200 words)*

This study's objectives were to assess the cost and operational effectiveness of state-of-the-art and emerging demining technologies, and to quantify the remaining challenges and potential benefits of developing new technologies. Its goals were to: 1) understand current demining operations and techniques; 2) identify the key cost and operational parameters which affect demining; 3) model demining operations and quantify the current methods in terms of these parameters; and 4) using this modeling tool, identify shortcomings and project potential improvements which could be provided by various new systems and technologies. All study objectives were met. A detailed tradeoff analysis was performed on a Mozambique demining scenario, using a variety of demining techniques and processes. Computer modeling results were in close agreement with reported field experiences, in terms of mine clearance rates, costs, and casualties. The computer model source code listing is provided.

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military counter-mine, humanitarian demining, landmines, detectors, probing, casualties, costs, tradeoff analysis, equipment, computer modeling, scenarios, bomb dogs, explosive detection

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COST AND EFFECTIVENESS MODELING FOR DEMINING OPERATIONS

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JANUARY 1996

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I.
EXECUTIVE SUMMARY

A. Objectives and Deliverables

This study's objectives were to assess the cost and operational effectiveness of state-of-the-art and emerging demining technologies, and to quantify the remaining challenges and potential benefits of developing new technologies. Its goals were to: 1) understand current demining operations and techniques; 2) identify the key cost and operational parameters which affect demining; 3) model demining operations and quantify the current methods in terms of these parameters; and 4) using this modeling tool, identify shortcomings and project potential improvements which could be provided by various new systems and technologies.

B. Approach

SPC employed a four step approach to accomplish of the objectives: 1) We first sought to define demining by researching and interviewing those directly involved. 2) Based on these understandings, we develop systems models of generic demining processes. 3) These demining processes then formed the basis for a computer model, which could rapidly vary parameters and trade off cost and effectiveness considerations. 4) Using this model, we conducted a preliminary assessment of where are the greatest potential for cost savings and improved effectiveness, and what challenges remain to be addressed.

C. The Problem.

Figure 1 (from Landmines: A Deadly Legacy) shows a map of the world, which gives the overall global demining challenge and the various degrees of severity by country and region. It appears that the only regions which are totally immune from the landmine threat are North America and Australia. Western Europe still suffers from the legacy of World War II, although at perhaps a trivial level compared to other regions of the world.

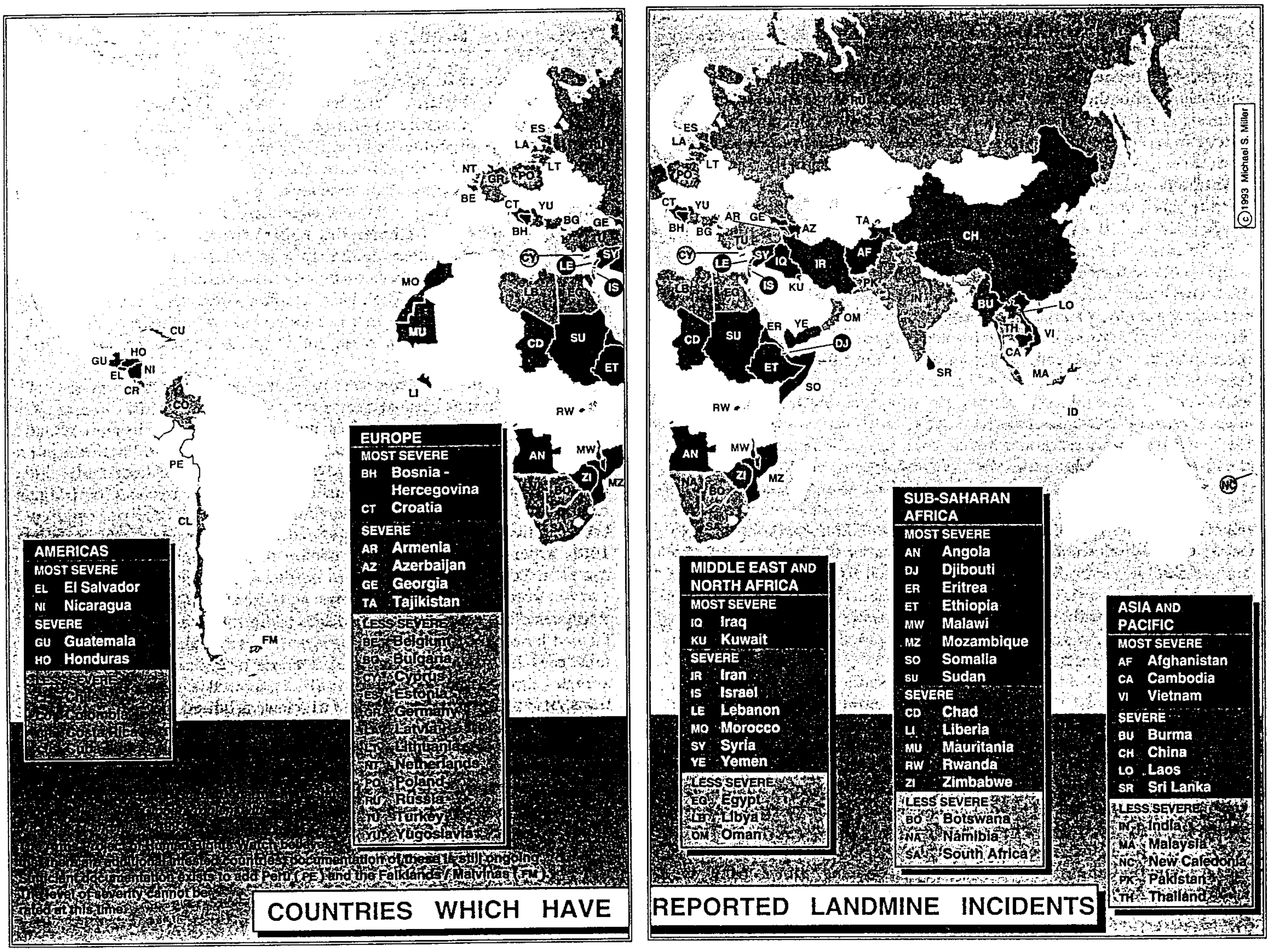

Figure 1
The Global Demining Challenge

The thirty-eight countries with severe and the most severe landmine problems are also suffering from severe economic and internal refuge problems, in part stemming from residual land mines which continue to deny the use of land and natural resources and terrorize those who dare to venture out from the limited safe havens. Neighboring countries and regions are also suffering economically from refugees displaced by these residual land mines and economic chaos.

The economic, social, and post-war conditions within these countries presents several challenges to the demining effort. In summary, these countries are poor and do not have sufficient resources to undertake demining projects or to maintain the necessary infrastructure to support demining. Knowledge of the precise location and numbers of residual landmines is not available, as evidenced by the many people who are killed or maimed each day by booby traps, landmines, and unexploded ordnance. As a result the demining process is labor intensive, expensive, and protracted, as every square foot of land must be checked for hidden dangers. Under these circumstances, some countries are estimated to require at least a century to clear.

D. Demining Technologies and Processes.

It must be realized that one demines a community, not simply a piece of land. The implications of this philosophy are far reaching in terms of the costs, technologies, and the schedule of a demining program. Communities comprise many specific locations: farms, roads, bridges, pasture, orchards, buildings, houses, water sources, and utilities. Therefore, the environmental disturbance or damage as a result of the clearance process should match the intended use of the specific location. This may dictate the use of different clearing processes and equipment which are most cost effective for a specific location. As examples, one may consider rolling roads, plowing farms, probing cemeteries, or employing bomb dogs to clear homes and buildings.

Some demining technologies may have more or less universal application in many specific locations, such as probes, metal detectors, and dogs. However, it is important not to destroy the long term usefulness of the location in an effort to make it mine free. For example, one should not plow or flail an orchard and kill all the trees in the name of demining efficiency. As a result, the most successful demining approaches have involved the most universally applicable and basic equipment and processes.

This study does not include an in-depth assessment of the cost effectiveness of using automated machinery or existing and developmental combat engineering equipment, which may be useful in counter-mine military operations. Combat engineering and earth moving equipment do not normally give high enough proof rates for demining. Comments made include: rollers do not conform to irregularities in the surface and therefore miss some mines; flails sometimes break the mines or push them deeper into the soil without detonation; and plows often push the mines aside without detonating them. These observations are more or less valid criticisms from a demining perspective. Nevertheless, a discussion of how heavy machinery and automated mine clearing processes could be adapted to a demining scenario is presented in the body of this report.

The technologies and processes for demining a community should address all of the components of a demining program: Survey - Detect - Verify - Neutralize - Rehabilitate. Surveying is the process of identifying and marking suspected mined areas for eventual clearing. Detecting is the process of entering a suspected minefield and precisely locating individual mines. Since some detection systems only indicate a suspected target, which could be either a mine or false alarm, each target must be verified. Following verification, some technique neutralize the hazard is then employed. Once the minefield is cleared of all targets, the location is then rehabilitated for its intended use. Special consideration of technologies should be made not only on their cost effectiveness face to face with the mines and UXO, but also on their training and maintenance requirements within the country in question, and their long term suitability for that country's demining infrastructure.

This study concentrated on evaluating the following currently employed surveying systems: 1) human intelligence or HUMINT; and 2) a system called MEDDS (Mecham Explosive and Drug Detection System), which employs dogs and a mine resistant vehicle for rapid area coverage. One emerging survey system was considered called ASTAMIDS (Airborne Standoff Mine Detection System), which employs a radar and infrared sensor system to identify both buried and surface placed mines and unexploded ordnance. In the cost and effectiveness analysis, each of these three survey approaches were used alone and in combination. HUMINT, MEDDS, and ASTAMIDS were each evaluated as a primary survey process. The combinations of HUMINT-MEDDS, HUMINT-ASTAMIDS, and MEDDS-ASTAMIDS were employed as supplemental surveys to see if overall effectiveness improved compared to using the primary process alone.

Detection, Verification, and Neutralization techniques evaluated were those currently employed in demining operations. Aspects of each of these three components of demining were incorporated into four basic clearance processes, representative of current demining operations: 1) probing alone, 2) metal detectors, 3) metal detectors and dogs, and 4) dogs and probing. Each of the six survey processes (primary and supplemental) were evaluated along with each of the four clearance processes for a total of twenty-four demining process evaluations. The processes were evaluated against a ten year demining program within a Mozambique scenario. Mozambique was selected as a candidate scenario because of its reported severe landmine problems and the availability of relevant information. A ten year demining program was established as a baseline from which to scale cost and effectiveness tradeoffs because current and planned demining programs are projected at increments of approximately ten years. Demining programs also require large up-front investments in equipment and training, the life-cycle costs for which should be amortized over a long duration project, such as ten years.

E. Modeling.

The computer model developed to evaluate the cost effectiveness of different processes and parameters comprises four modules: 1) Scenario Development, 2) Survey, 3) Clearance, and 4) Cost Analysis. This organization to the model is consistent with the community oriented demining philosophy and incorporates the distinct elements involved in a demining program. Within the scenario development, a distribution of landmine concentrations can be postulated, which may represented the likely situation with a particular country or region. Using a flexible scenario approach in the modeling permits the survey process to be fully challenged and evaluated from a cost and effectiveness perspective. Survey outputs include the distribution mines which were identified by the survey technique, and the amount of un-mined area which will also end up being cleared, due to errors in the survey process. The results of the survey, which are now scenario dependent, are then passed on to the clearance module. Each candidate clearance process is evaluated against the survey results to determine the level of clearance achieved. Finally, the cost module calculates the total cost and duration of all survey and clearance processes considered for that scenario, based on cost and level-of-effort (LOE) input parameters.

This model is sufficiently flexible and robust to permit a multitude of survey and clearance processes -- either existing, emerging, or postulated -- to be evaluated against real world demining scenarios. For this reason, this model is useful not only for achieving the stated objectives of this study, but also as a planning and evaluation tool for ongoing and upcoming demining efforts.

F. Findings and Recommendations.

Tables 1 and 2 present the detailed results of the twenty-four survey-clearance combinations considered in this study, for a real world Mozambique scenario. This specific scenario considers that 1 million mines are present within the 39,350 square kilometers of inhabited area of that country, and that all terrain will be cleared within a 10 year program. In addition, 8% of the landmines will be plastic or low-metallic and, therefore, un-detectable by currently employed mine detectors. This aspect of the scenario serves to highlight the unique challenge facing deminers and the need for effective plastic and low metallic mine detectors. The input parameters supporting the survey and clearance processes are a compilation of best estimates, based on the research conducted during this study. The chosen output format is based on those items of information of most interest to the demining community.

TABLE 1A.
Demining Technology Analysis Results for a Mozambique Scenario: Process Costs

Sheet1

survey type	clearance type	detection probability	% mines surveyed	% cleared by detection	unmined area km2	survey cost $	clearance costs $	total costs $	survey $/km2	clearance $/km2	total cost/area $/km2	survey $ cost/mine	clearance $ cost/mine	total $ cost/mine
Humint			95.00		13,000	4.1 million			104			4.32		
	probing	0.999		94.9			71.3 billion	71.3 billion		1.81 million	1.81 million		75,132	75,136
	detectors	0.92		87.4			1.7 billion	1.70 billion		0.43 million	0.43 million		1,945	1,949
	dogs & detectors	0.95		90.2			875 million	879 million		22,000	22,100		1,001	1,006
	dogs & probing	0.95		90.2			4.03 billion	4.04 billion		0.102 million	0.102 million		4,610	4,624
MEDDS			99.99		6,215	75 million			1906			75		
	probing	0.999		99.9			34 billion	34.07 billion		0.86 million	.862 million		34,034	34,109
	detectors	0.92		92			859 million	934 million		22,000	24,000		934	1015
	dogs & detectors	0.95		95			453 million	528 million		12,000	14,000		477	556
	dogs & probing	0.95		95			2.04 billion	2.12 billion		54,040	56,212		2,148	2,232
airborne			99.5		1,391	3.6 million			91.5			3.6		
	probing	0.999		99.4			7.76 billion	7.764 billion		0.92 million	0.92 million		7,807	7,811
	detectors	0.92		91.5			264 million	268 million		7,000	7,100		289	293
	dogs & detectors	0.95		94.5			150 million	154 million		4,000	4,100		159	163
	dogs & probing	0.95		94.5			606 million	610 million		16,160	16,240		642	646
Humint-MEDDS			94.99		5,904	29 million			737			29		
	probing	0.999		94.9			32.5 billion	32.53 billion		0.83 million	0.831 million		34,247	34,278
	detectors	0.92		87.4			816 million	845 million		21,000	22,000		934	967
	dogs & detectors	0.95		90.2			431 million	460 million		11,000	12,000		478	510
	dogs & probing	0.95		90.2			1.94 billion	1.97 billion		49,500	51,400		2,152	2,184
Humint-airborne			94.92		459	5.3 million			135			5.3		
	probing	0.999		94.4			2.65 billion	2.655 billion		70,000	70,132		2,807	2,813
	detectors	0.92		87			145 million	150 million		4,000	4,100		167	172
	dogs & detectors	0.95		89.8			88.6 million	93.9 million		2,300	2,400		99	105
	dogs & probing	0.95		89.8			320 million	325 million		8,132	8,259		358	363
MEDDS-airborne			99.49		220	75.8 million			1926			75.8		
	probing	0.999		99.4			1.35 billion	1.42 billion		34,000	36,000		1,358	1,428
	detectors	0.92		91.5			120 million	196 million		3,000	5,000		131	214
	dogs & detectors	0.95		94.5			76.7 million	153 million		2,000	4,000		81	162
	dogs & probing	0.95		94.5			259 million	335 million		6,600	8,500		274	355

TABLE 1B.
Demining Technology Analysis Results for a Mozambique Scenario: Process Effectiveness

Sheet1

survey type	clearance type	detection probability	% mines surveyed	% cleared by detection	# people continuous LOE	#people continuous LOE	# systems continuous LOE	# systems continuous LOE	casualty probability (detection)	casualty probability (neutralization)	casualties people	casualties systems	undetected mines remaining
Humint			95.00		55		0						
	probing	0.999		94.9		1.011 million		0	0.001 prober	0.01	10,440	0	50,000
	detectors	0.92		87.4		22,330		0	0.004 detector	0.001	4,674	0	122,200
	dogs & detectors	0.95		90.2		11,024		848 dogs	0.00005 dog	0.001	4,654	48 dogs	94,152
	dogs & probing	0.95		90.2		54,080		2704 dogs	0.00005 dog	0.001	1,804	48 dogs	97,050
MEDDS			99.99		160		40						
	probing	0.999		99.9		484,632		0	0.001 prober	0.01	10,990	0	100
	detectors	0.92		92		11,209		0	0.004 detector	0.001	4,920	0	76,000
	dogs & detectors	0.95		95		5,538		426 dogs	0.00005 dog	0.001	4,900	50 dogs	46,000
	dogs & probing	0.95		95		27,040		1,352 dogs	0.00005 dog	0.001	1,900	50 dogs	49,000
airborne			99.5		4		1						
	probing	0.999		99.4		109,152		0	0.001 prober	0.01	10,935	0	5,000
	detectors	0.92		91.5		3,212		0	0.004 detector	0.001	4,895	0	81,020
	dogs & detectors	0.95		94.5		1,612		124 dogs	0.00005 dog	0.001	4,875	50 dogs	51,020
	dogs & probing	0.95		94.5		7,800		390 dogs	0.00005 dog	0.001	1,940	50 dogs	53,955
Humint-MEDDS			94.99		107		13						
	probing	0.999		94.9		458,739		0	0.001 prober	0.01	10,440	0	50,100
	detectors	0.92		87.4		10,659		0	0.004 detector	0.001	4,674	0	122,200
	dogs & detectors	0.95		90.2		5,226		402 dogs	0.00005 dog	0.001	4,655	47 dogs	94,200
	dogs & probing	0.95		90.2		25,840		1,292 dogs	0.00005 dog	0.001	1,805	47 dogs	97,050
Humint-airborne			94.92		59		1						
	probing	0.999		94.4		37,296		0	0.001 prober	0.01	10,390	0	50,800
	detectors	0.92		87		1,639		0	0.004 detector	0.001	4,667	0	126,203
	dogs & detectors	0.95		89.8		858		66 dogs	0.00005 dog	0.001	4,648	47 dogs	98,203
	dogs & probing	0.95		89.8		4,000		200 dogs	0.00005 dog	0.001	1,800	47 dogs	101,051
MEDDS-airborne			99.49		164		40 MEDDS+1 air.						
	probing	0.999		99.4		18,648		0	0.001 prober	0.01	10,935	0	5,100
	detectors	0.92		91.5		1,298		0	0.004 detector	0.001	4,895	0	81,020
	dogs & detectors	0.95		94.5		676		52 dogs	0.00005 dog	0.001	4,875	50 dogs	51,020
	dogs & probing	0.95		94.5		3,160		158 dogs	0.00005 dog	0.001	1,890	50 dogs	54,005

Based on these analysis results, several conclusions and recommendations can be identified:

Conclusions:

1. Significant demining cost reductions are achievable by employing more advanced survey technologies. This results primarily from the great reduction in un-mined area which must be checked for mines, due to survey inaccuracies.

2. Survey inaccuracies, even with detection rates in the mid to high 90th percentile, result in large numbers of remaining undetected landmines. Short of sending bomb dogs (MEDDS) throughout the entire inhabited country, most survey technologies fail to ensure very high clearance rates.

3. Probing alone effectively clears every mine and minefield identified by the country survey (99.9% proof rate), and if dogs (MEDDS) is used as the survey process, 99.9% of all mines will be cleared. However, this is achieved at an enormous human and financial cost.

4. If all mines were detectable my metal detectors, the dog-detector clearance process is the most cost effective technology for achieving nearly a 95% proof rate.

5. In the presence of plastic and low-metallic mines, the reliance on metal detectors presents a serious casualty risk. Under these circumstances, probing must be employed, with the resulting decrease in efficiency and increase in clearance costs. The dogs-probing process more than doubles costs over dogs-detectors when using the most efficient survey process (MEDDS-airborne). For other survey processes, clearance costs increase dramatically.

6. Supplemental surveys will not increase the number of mines detected by the survey. However, large clearance cost reductions are obtainable by using a supplemental survey, if leaving slightly more undetected and uncleared mines is acceptable.

7. Although survey costs are relatively small compared to clearance costs, the accuracy of the survey process has the greatest impact on total clearance costs. This tradeoff highlights the need of the survey process to minimize the amount of un-mined area that must be cleared due to survey inaccuracies.

Recommendations:

1. Develop rapid remote sensing survey processes with effectiveness well beyond the limited capabilities of human intelligence. Multi-spectrum airborne detection systems may offer promising emerging technology. An effective near term survey process should include the use of bomb dogs.

2. Develop an effective plastic and low-metallic mine detector system, which also detects conventional metallic mines. The availability of such a device will greatly reduce demining casualties, while boosting clearance efficiency at greatly reduced cost. A near term approach to this problem may involve performing more in-depth characterization of the effectiveness of bomb dogs, and developing knowledge on when dogs cannot detect mines, and how to improve the pinpoint accuracy of a dog detection.

3. Develop improved protective clothing and greater standoff neutralization technologies for deminers. The clearance process still involves an individual excavating and neutralizing a mine in close proximity to his body. Regardless of high survey and detection system effectiveness, an injury is currently inevitable when constantly handling such large quantities of mines and unexploded ordnance at the neutralization phase of demining.

II.

THE NATURE OF THE PROBLEM

A. Definition

Demining is that set of related functions required to render mined areas safe for civil use. Demining operations can be accomplished by 1) expatriate contractors and or expatriate governmental and non-governmental entities, 2) indigenous governmental entities and or contractors, or by 3) some combination of these approaches. The difficulty with the second approach, which is preferred, is that, as a rule, societies with the most extensive mine problems have the least capacity, in terms of expertise and or resources, to deal with it. As a result, most demining operations employ variations of the third approach; usually employing expatriate resources to conduct time critical demining and to assist in development of an indigenous demining capability. Kuwait is the best noted exception to this rule.

Demining operations are different from military countermine operations. The principal differences are: 1) countermine is conducted during hostilities while demining is conducted subsequent to hostilities; 2) countermine operations are often conducted under fire and at the least opportune times—at night and in adverse weather—to minimize casualties and or maximize surprise, demining operations are generally conducted under favorable conditions; 3) demining requires almost total clearance, countermine does not; and 4) keeping collateral damage to a minimum is more an imperative in demining than in countermine operations. The objective in countermine operations is generally to clear a relatively narrow lane of mines, on the order of 8 m in width and 100 m in length, as rapidly as possible. Additionally, countermine operations do not necessarily require mine neutralization, simply displacing them from the desired lane is sufficient. The objective of demining, on the other hand, is neutralizing all the mines within a generally large geographic area—usually measured in square kilometers—with a high degree of surety; 99 percent or better being desired.[1] As demining's core objective is returning mined areas to civil use, and because mines are principally found on or near infrastructure, it is imperative to keep collateral damage, consequent to demining, to a minimum.

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[1] Landmines: A Deadly Legacy, p. 236

B. Dimensions

As a consequence of both insurgency and conventional warfare, landmines pose a significant problem in a large part of the world. Based in large part on UN figures, the US Department of State estimates there may be as many as 85 - 90 million of these mines.[2] This figure is probably high. The true extent of the landmine problem is unknown. For example, Human Rights Watch notes:

> ...the December 1992 United Nations estimate of 2 million mines ...has no scientific basis; ... The total number of landmines in Mozambique is certainly in the tens of thousands, and probably in the hundreds of thousands.[6]

There are a number of reasons for this. First mines are by design and nature of employment hard to detect. Additionally, while military organizations routinely record the location of their minefields, this practice is not always adhered to and data indicating minefield locations may be lost. Insurgents are normally concerned with such niceties.

Even if the true figure is only half as large as that cited by the State Department, mines would still pose a significant problem. Mines are assessed to cause some 150 civilian casualties per week,[3] of which 15 may be fatalities.[4] But injury and death resulting from direct encounters are only part of the cost inflicted by mines. By rendering transportation and economic infrastructure unusable, mines also exact an economic and political toll. In general, the most significant mine problem is found in Africa, the Middle East, and Southwest and Southeast Asia. Table 2 provides some sense of the scale of the problem.

Mines are generally emplaced in one of three ways. They may be buried from as little as 2 cm to more than 40 cm deep. The former being more likely in an environment in which manual as opposed to mechanical means of emplacement are employed. Mines may be also partially buried, such as the Italian Valmara 69, with fuze prongs exposed. Mines may also simply be laid on the surface of the ground or, in the case of the American M18 and Russian MON and POMZ series of mines, staked with the lethal mechanism elevated above the ground. Some mines, such as the Italian VS-50, may also be laid in shallow water, such as in fords. Given the opportunity, those emplacing mines will attempt to conceal them. Surface laid mines will normally have some neutral or even camouflage finish to help blend them into the background.

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[2] Hidden Killers: The Global Problem With Uncleared Landmines, p. 3

[6] Landmines in Mozambique, p. 14

[3] Ibid., p. 2

[4] Landmines: A Deadly Legacy, p. 142

Table 2 implies that mines are uniformly distributed in a given geographic area. They are not. Mine density may vary by region and will vary depending on land use. For example, two provinces of Mozambique that together comprise roughly a fifth of its total area, Niassa and Cabo Delgado, have a comparatively minor mine problem.[7] Mines, specifically those of most concern to demining, will for the most part be found where the population is. Mines are principally placed in such a manner as to terrorize or to deny use of terrain or, more correctly in scenarios of interest to demining, that which is on that terrain, such as infrastructure. Surveys conducted by the International Committee of the Red Cross (ICRC) and Africa Watch in Angola and Mozambique indicate the highest concentrations of mine incidents are found on or near unimproved roads and trails, followed by improved roads, inhabited areas, and finally fields and other areas. These findings are summarized in Table 3.

Country	Area (km^2)	Estimated Number of Mines	Mines per km^2
Sudan	2,500,000	500,000 - 2,000,000	.5
Eritrea/Ethiopia	470,000	300,000 - 1,000,000	.5
Nicaragua	130,000	130,000	1
Somalia	637,000	1,200,000 - 2,000,000	2.5
Mozambique	787,000	2,000,000	2.5
Angola	1,250,000	9,000,000	7.2
Former Yugoslavia	256,000	2,500,000 - 3,700,000	11.3
Iraq	435,000	5,000,000 - 7,000,000	11.5
Afghanistan	650,000	9,000,000 - 10,000,000	14.7
Cambodia	181,000	4,000,000 - 7,000,000	30.4
Kuwait	6,200	5,000,000 - 7,000,000	373.5

Table 2. Scale of the Problem[5]

[7] Landmines in Mozambique, p. 15

[5] Derived from information found in Hidden Killers

Inhabited areas should not be construed to mean in urban areas, but rather small towns and villages and at points next to them likely to attract large groups, such as water sources. In his examination of the mine problem in Hidden Killers, David Gowdy notes that:

> Our survey indicates that landmines are largely a rural, third world problem. ... Urban mining is the exception rather than the rule. Mines are most commonly found in rural border areas, around rural infrastructure such as electric lines, water plants, and bridges, around military installations in combat zones, and along roads. Terror mining of small towns and villages is common[5]

Fully two thirds of the mine incidents in Angola were found to have occurred within five kilometers of a village or town.[6]

	Land Use				
	Unimproved Roads and Trails	Improved Roads	Inhabited Areas	Fields	Unknown
ICRC (Angola)	69%	15%	16%	-	0%
Africa Watch (Angola)	61%	19%	9%	5%	6%
ICRC (Mozambique)	58%	23%	-	16%	3%

Table 3. Distribution of Mine Incidents[8]

Another point to be noted is that individual landmines do not appear to be the major problem so much as minefields, perhaps more appropriately clusters of four (4) or more mines. The example cited in Landmines in Mozambique of 500 mines in 34 clusters appears more the norm than the individual mine.[9]

While these data are specific to Mozambique and Angola, this pattern can reasonably be expected to apply to other regions where the mine problem is primarily the result of insurgencies, rather than conventional warfare.

This should not be construed to imply that minefield configurations more typical of conventional conflicts will not be found in the aftermath of insurgencies. In Somalia it is

[5] Hidden Killers, p. 7
[6] Landmines: A Deadly Legacy, p. 156
[8] Landmines: A Deadly Legacy, pp. 153 - 154
[9] Oxfam, "Recce Notes - Nissa Province," undated (1993), p. 15

estimated that some 70% of the mines are to be found in barrier minefields along the Ethiopian border laid by the Somali government to hinder insurgent forces crossing the border from Ethiopia into Somalia.[10] Large barrier minefields are, however, an intrinsically easier problem to deal with, from the perspective of location and avoidance, than randomly placed clusters of mines.

If one approaches the demining problem from the perspective of where mines are most likely found and do the most harm, the real extent of the problem in a given area becomes clear. Dense human habitation as well as the vast majority of a society's economic and transportation infrastructure is found on its arable land. In Mozambique this is roughly one third of the total land area, about 236,100 km^2. Actual land under actual cultivation will be less than total arable land. It may be much less. The World Bank, for instance, estimates that only about 30,000 km^2 are under cultivation in Mozambique, slightly less than four (4) percent of total land area. Mozambique's transportation infrastructure—improved, unimproved roads, and railroads—accounts for another 238 km^2, if one assumes a uniform 8 meter clearance requirement. There are no good figures for total area occupied by towns and villages. However, based on the extent of land under cultivation and transportation infrastructure, one could reasonably argue that the area of Mozambique of principal concern to a demining operation is about five (5) percent of the total land area or 39,350 km^2. This decreases the total land area to be demined by 95% but increases mine density. If one assumed 1,000,000 mines, by all accounts a more reasonable figure than the UN's initial estimate of 2,000,000, this reduction in area would increase mine density from 1.3 per km^2 to 25.4 per km^2.

Actual area to be cleared is even less than this, as Figure 2 indicates. Based principally on the pilot road clearing project conducted by Gurkha Security Guards, Ltd., in Sofala province Mozambique in 1993,[11] it is reasonable to expect that information derived from local inhabitants, former combatants and local authorities can reduce the actual area to be searched and cleared by as much as two thirds. In Mozambique this translates to some 12,986 km^2, which would increase mine density of 77 mines per km^2, again assuming 1,000,000 total mines.

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[10] Landmines: A Deadly Legacy, p. 223

[11] Landmines in Mozambique, 80-83

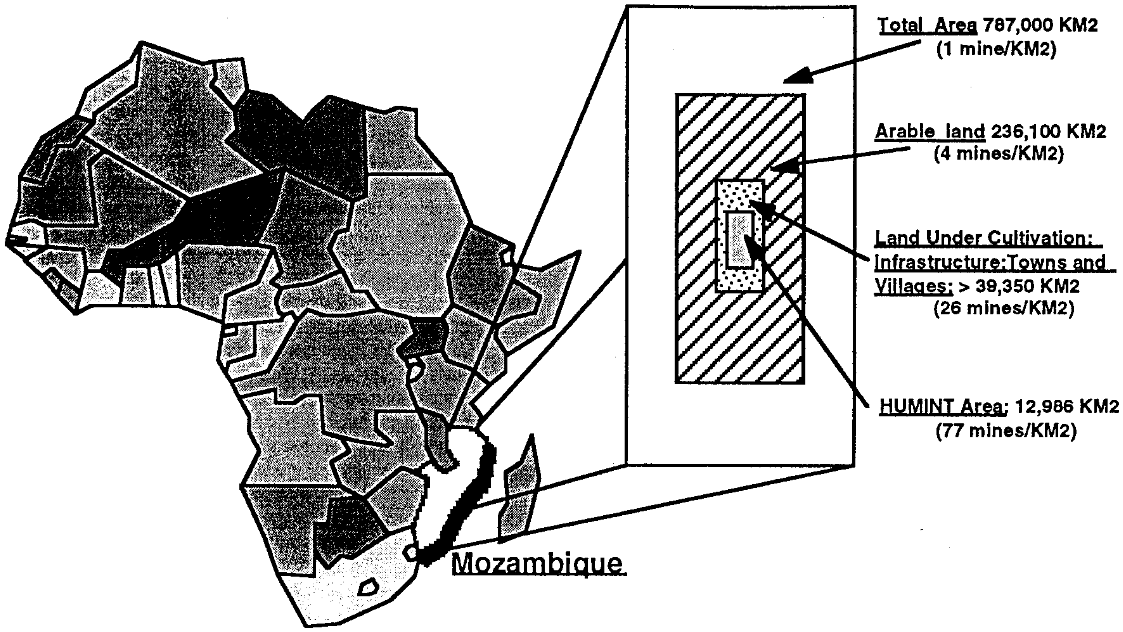

Figure 2. Actual Area Requiring Clearance

Applying what is known about mine employment, the distribution of these 77 mines should be reasonably similar to that proposed in Figure 3. Mines would be placed in clusters on paths and trails leading to fields, to sources of water, and on roads and trails between towns and villages to disrupt communication.

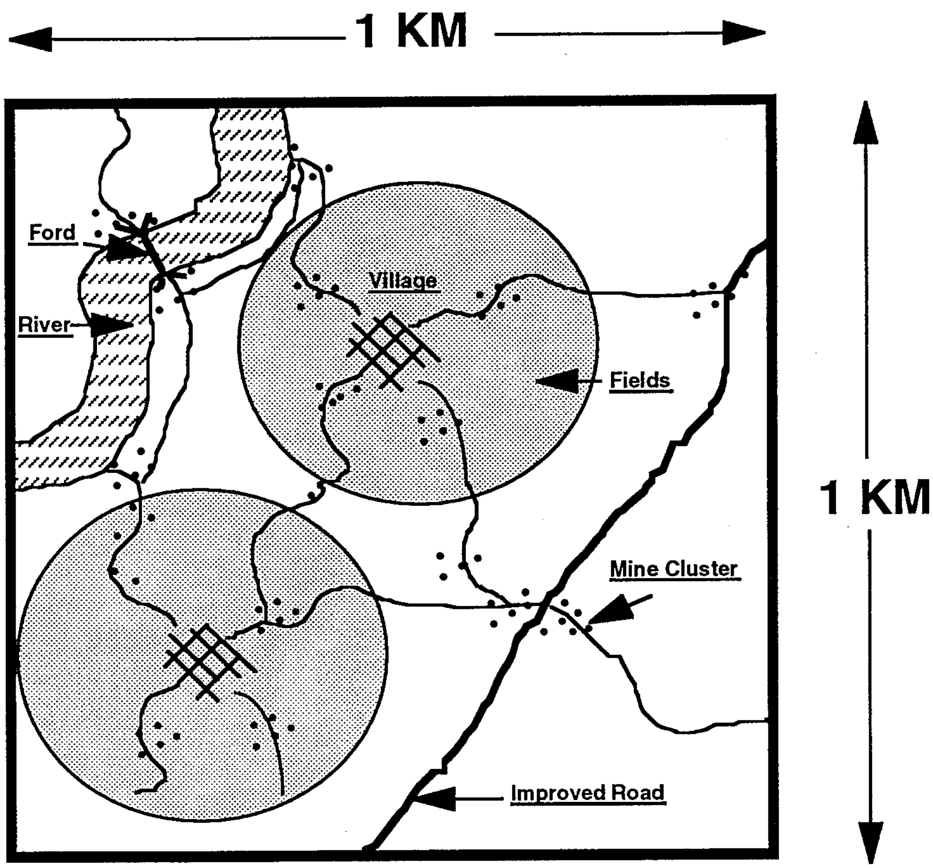

Figure 3. Anticipated Mine Distribution

The mine problem is compounded by the fact that there are a variety of different mines requiring different technologies and techniques to detect and neutralize. There are two basic types of mines that are considered in this study— antipersonnel (AP) and anti-vehicular or tank (AT) mines. Of these two, AP mines are by far the most prevalent in demining scenarios. For example, an Africa Watch Study conducted in 1992, determined that only 4 percent of the mine incidents in Angola were attributable to AT mines. A comparable study by the ICRC attributed 16 percent of the mine incidents in Angola to AT mines.[12]

Complicating the problem of mine clearance are that AP and AT mines are often combined a given mine cluster, and that unexploded ordnance (UXO) may be intermingled with mines, more often as the result of conventional conflict than insurgency, and that UXO's are in some instances modified for employment as mines.

The metal content and arming mechanisms of mines vary, compounding the problem even further from the perspective of detection and neutralization. UXOs by their nature are

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[12] Landmines: A Deadly Legacy, p 155

invariably of high metal content, and consequently readily detectable by metallic mine detectors. Some mines, such as the US M14 and the Italian VS-50, have such a low metal content as to render current metallic mine detectors all but useless.

There are essentially three types of arming mechanisms: 1) influence-activated by some type of signature, e.g., electromagnetic to include emanations from metallic mine detectors; 2) contact, including pressure, disturbance and tripwire activation; and, reportedly, 3) photonic—activated by exposure to the sun. Of these three categories of arming mechanisms, the ones of most concern in demining scenarios are those activated by contact. Mechanisms activated by pressure and tripwires are of concern.

Command detonation as an arming mechanism is of no concern in demining because such mines are assumed to be unmanned. They are therefore characterized according to the arming mechanism of the anti-handling device, if any, affixed to them. Mines, and UXOs for that matter, are often equipped with anti-handling devices or booby traps to make disarming them difficult if not impossible. Mines such as the Italian VS-50 have integral anti-handling devices.

It must be noted that many, if not most, command detonated mines, such as the US M18, may also be activated by tripwires. The Russian MOM series command detonated mines may also be activated by a seismic sensor.

While trip wires improve the likelihood that a mine will be detected, they also increase the chance that it will be encountered. For example while the fuze prongs on the Yugoslav PROM-1 cover an area on the order of .01 m^2, this mine's 16 m trip wire extends the area over which it may be encountered and detonated to 1,607 m^2. The hazardous area of the Russian MON series mines may be even greater, if the UMK seismic sensor is employed.

Table 4 lists the characteristics of some of the most widely proliferated mines. In general, AP mines have diameters on the order of 100 mm or less—noted exceptions being the Russian MON-100 and -200—while AT mines are normally three times that size. Explosive loading in AP mines is normally less than .5 kg—the MON series again being exceptions—while the explosive loading of AT mines is ten times greater. Artillery and or air delivered scatterable mines are generally smaller with less explosive, but are not as widely proliferated and, hence, representative as the mines presented in Table 4.

Type	Emplacement	Explosive Charge	Materials	Size	Fuze
		AP	Mines		
M-14 (US)	buried	.029 kg	plastic	height 40 mm diameter: 56 mm	pressure
M-16 (US)	partially buried	.454 kg	metallic	height 199 mm diameter: 103 mm	pressure or trip wire
M18A1 (US)	surface emplaced	.680 kg	plastic	height: 83 mm length: 216 mm width: 35 mm	trip wire or command
MON (Russia)	surface emplaced	MON-50 - ~.680 kg MON-100 - 5 kg MON-200 - 12 kg	plastic	MON 50- height ~ 83 mm; length ~216 mm; width ~35 mm MON-100 - diameter: 220 mm MON-200 - diameter: 520 mm	trip wire, command or seismic influence
OZM (Russia)	partially buried	.075 kg	metallic	height: 120 mm diameter 75 mm	pressure, trip wire or command
PMD-6 (Russia)	Buried	.200 kg	wooden	height: 64 mm length 200 mm width 89 mm	pressure or trip wire
PMN (Russia)	buried	.240 kg	plastic	height 56 mm diameter 112 mm	pressure
POMZ-2 (Russia)	surface emplaced (staked)	.075 kg	metallic	height 135 mm; diameter 64 mm	trip wire
Type 72 (China)	surface laid or buried	.034 kg	plastic	height: diameter:	pressure
Valmara 69 (Italy)	partially buried	.420 kg	plastic	height: 205 mm diameter 130 mm	pressure or trip wire
VS-50 (Italy)	surface laid or buried	.043 kg	plastic	height: 45 mm diameter 90 mm	pressure
		AT	Mines		
TM/TMN-46 (Russia)	surface laid or buried	5.95 kg	metallic	height: 91 - 110 mm diameter 304 mm	pressure
TM-62 (Russia)	surface laid or buried	7.00 kg	metallic, plastic, wooden, cardboard	height: 115 mm diameter 315 mm	pressure or magnetic influence
Type 72 (China)	surface laid or buried	5.40 kg	plastic	height: 100 mm diameter 270 mm	pressure

Table 4. Common Mines

If one were to attempt to capture all the potential demining scenarios that might be encountered, based on the environment and the nature of the mine threat, it would result in a matrix similar to that depicted in Table 5.

Potential demining scenarios are defined principally by the environment, primarily terrain and vegetation because weather is a factor that can usually be controlled for, and the nature of the mine threat. There are four basic types of terrain. Improved roads and inhabited areas are unique in that contour, soil type and water are not significant complicating factors. An unimproved road or trail, on the other hand, may differ little from the surrounding terrain except in its comparative lack of vegetation.

The effects of contour, texture —according to *Webster's New World Dictionary* "...the arrangement of the particles or constituent parts of any material as it affects the appearance or feel of the surface; structure, composition, grain, etc."— vegetation, soil type, and water are considerations that must be addressed but will vary with the technologies and techniques employed in demining. They affect both mobility, and hence may limit mechanical means of mine detection and neutralization, and the ability of different technologies to detect mines. Texture, with respect to the electromagnetic spectrum, is principally of concern with respect to reflectivity and absorption.

Another environmental factor, in addition to weather that will be assumed away for purposes of this study is the condition of the local transportation and communications infrastructure. While infrastructure damage will affect the pace of demining, infrastructure repair, besides reclamation consequent to mine clearance itself, is not a demining function.

A final point is that a single region to be demined may span the entire spectrum of scenarios. In Mozambique, for example, natural ground cover varies from tropical rain forest to savanna with elevations from near sea level to almost 1,600 meters. The only types of mines not encountered in Mozambique, generically, were influence and photonic. Further, UXOs do not appear to have been a significant threat.

III.

DEMINING FUNCTIONS AND COST DISTRIBUTION

A. Functions

While expatriate entities may be employed to perform emergency demining to clear lines of communications (LOCs) and perhaps staging areas until an indigenous capability is established, the preferred approach is providing indigenous authorities the capability, in terms of resources and training, to conduct demining themselves. This is both official UN and US policy. There are seven basic functions that must be performed to provide such a capability. These are: 1) planning and 2) resource collection; 3) survey of the country to be assisted to determine resource and training requirements; 4) securing staging areas and including LOCs, to include limited mine clearance if necessary and 5) preparing staging areas as logistics and operations centers and training sites for indigenous personnel; 6) training indigenous personnel to conduct mine clearance and providing mine awareness training for the population at large; and 7) the actual conduct of large scale mine clearance operations by indigenous personnel. The relation of these functions is depicted in Figure 4.

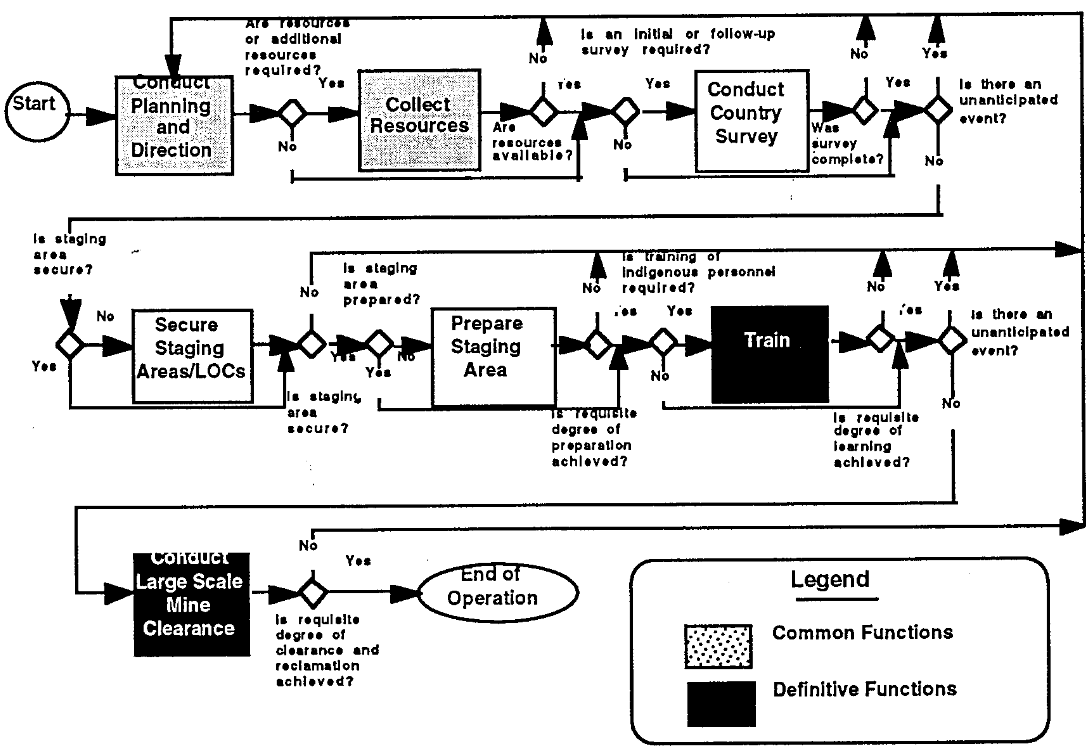


Figure 4. Demining Functional Systems Model

Planning and resource collection are common to all other functions . For example, one assesses training requirements, plans training and then collects the resources necessary to execute that plan. If on completion of training it is determined that the requisite degree of learning was not achieved, then a new plan is developed to correct deficiencies and additional resources are gathered, if required. A key output of the planning function is the prioritization of mine clearance operations, based on mine and population density and the political, economic and humanitarian cost of deferring clearance of specific areas.

B. Costs

Assessing cost distribution is difficult. UN costs' estimates are based on a rule of thumb per mine removed of $300 to $1,000. Contractors are reluctant to share cost models. Sufficient open source information, however, does exist to permit a rough estimate to be made for the allocation of funding within an overall demining program.

Conducting an initial country survey can take as little as a few weeks or at most months. It principally consists of small teams of experts going to a country to determine its needs based principally on discussions with local authorities combined with some amount of direct observation. The United States Special Operations Command's (USSOCOM) country survey and follow-up discussions with authorities in Eritrea, for example, consisted of an initial ten (10) day evaluation by two (2) men with a ten (10) day follow-up with a seven (7) man team. The Mine Advisory Group's (MAGs) initial assessment of the mine problem in Angola also took less than a month.

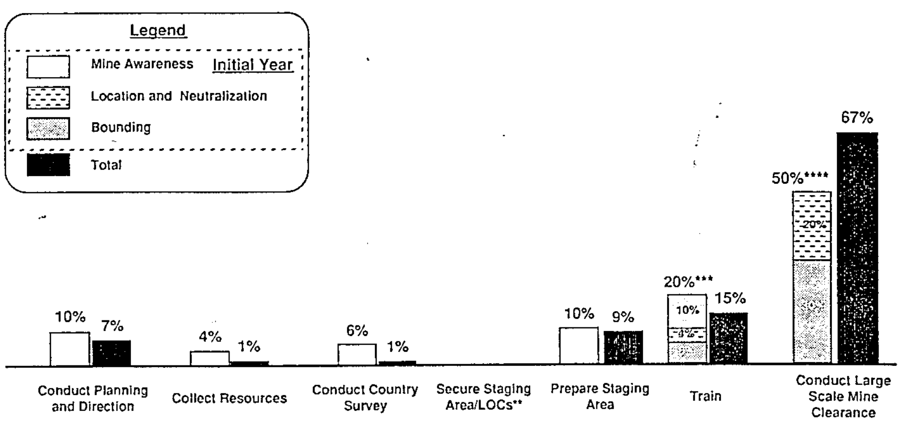
Table 5. compares the percentage of initial year costs allocated to the seven demining functions in the: 1) MAG Emergency Proposal for Landmine-Related Project in Angola, January 28, 1994; 2) the Cost Estimates for FY94 DoD Humanitarian Demining Assistance provided by USSOCOM/CENTCOM to Eritrea and PACOM to Cambodia, including an estimated $2,000,000 in mine detection/clearance equipment to be provided the Cambodian government; and 3) UNOMOZ1 for initial year demining costs in Mozambique, supplemented by information extracted form Landmines A Deadly Legacy. Figure 5. shows this comparison in graphic form. For each function area, the initial year and subsequent year allocations are shown side-by-side. While direct comparison of these efforts is difficult, for example the FY94 DoD Humanitarian Demining Assistance does not include salary costs and none of these sources breaks costs out exactly in the functional categories proposed in this paper, it is readily apparent that by far the largest portion of resources is allocated to actual mine clearance followed by training.

The MAG Emergency Proposal for Landmine-Related Project in Angola provides somewhat more insight in actual cost breakdown. With respect to training costs, 6% are associated with mine field bounding and mine location, 4% with neutralization, and 10%

with mine awareness. With respect to mine clearance, 30% of the costs are associated with minefield bounding and mine location and 20% with neutralization.

FUNCTION	ORGANIZATION			
	MAG	PACOM	CENTCOM	UNOMOZ1
Planning and Direction	10%	7%	UNK	UNK
Resource Collection	4%	UNK	UNK	UNK
Country Survey	6%	UNK	1%	UNK
Secure Staging Areas and LOCs	0%	0%	UNK	UNK
Prepare Staging Areas	10%	UNK	UNK	UNK
Train	20%	25%	UNK	13%+
Conduct Large Scale Mine Clearance	50%	77%	55%	66%

Table 5. Resource Requirements as Percentage of Initial Year Budget



Notes:

* As % of budget
** Captured in large scale mine clearance.
*** Salary only. Set-up and travel costs included in staging area preparation . 40% of total training costs are the salaries of the mine awareness personnel for the entire year, not just the period of their training. Mine awareness training of the population is a key training task.
**** 60 % of total is salary. 45% of total is expatriate salaries. ~ 5 % of total is salary and equipment--e.g. trauma kits--for ancillary personnel , medics,drivers, translators, etc.
***** 52% of total budget is salary.

Figure 5. Resource Requirements as Percentage of Initial Year Budget

The remainder of this study will focus on mine clearance operations. Of the seven demining functions, it is the most time intensive and costly; consuming over half of a demining operation budget.

IV. CURRENT MINECLEARING TECHNOLOGIES, TECHNIQUES, AND COSTS

Mine clearance itself consists of five sub functions. These are: 1) minefield bounding or surveying, which involves locating the areas to be cleared; 2) precise location of mines and UXOs, this requires both detection and verification that the object detected is a mine or UXO; 3) neutralization of mines and UXOs; 4) proofing, or quality assurance, a high degree of surety in the location and neutralization processes may preclude the need to proof; and 5) reclamation or rehabilitation of the terrain for use as intended by the local population. The relationship of these functions is depicted in Figure 6.

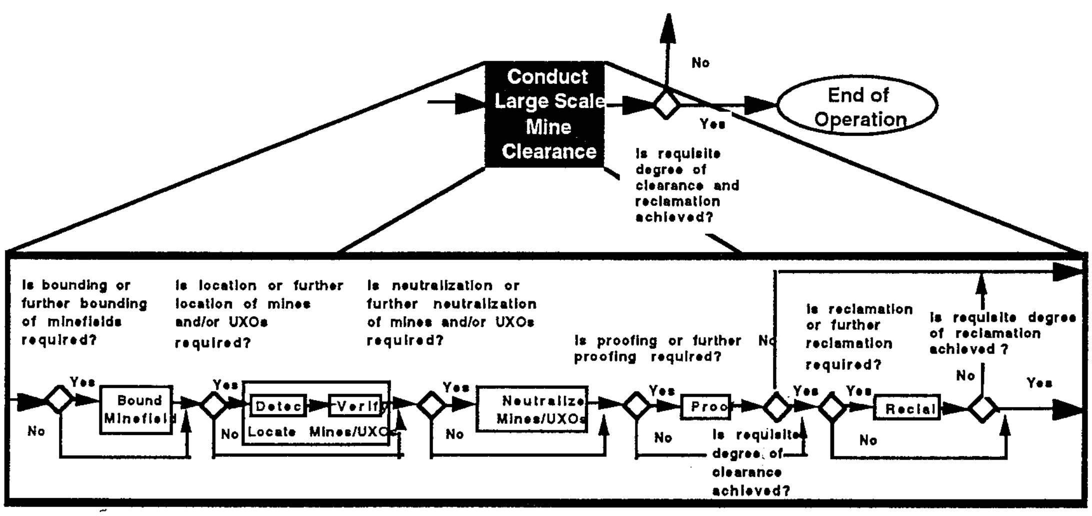


Figure 6. Mine Clearance Functions

Current mine clearance technologies and techniques are manpower intensive and dangerous. Handheld metallic mine detectors, manual probing and dogs trained to detect mines are the most common methods of mine detection. Even when dogs are employed, metal detectors and probes are normally required to pinpoint mine location, while neutralization involves either manual excavation and then either removal for remote destruction or destruction in situ, employing explosives.

Mine neutralization technologies developed for military countermine operations, while inherently safer and more rapid, such as explosive line charges and flails, are terrain limited, too destructive and or have a surety level too low for demining. Mine plows, rather than neutralizing mines, simply move them out of the way, and in that process may cause the to detonate or arm. Further, a number of mines, such as the Italian VS-50, are constructed to resist the over pressure, that is the principal operating mechanism of systems like explosive line charges. Consequently UNOMOZ1, A Mine Clearance Plan for Mozambique, notes:

> ...the clearance rate for these (mechanical) devices will probably be 80 percent, considerably lower that the 99.9 percent clearance needed for the re-introduction of refugees or displaced persons into the area.[13]

In the end the most efficient means of mine neutralization today remains the individual deminer.

Because these technologies and techniques are manpower intensive they are time consuming and costly, as well as dangerous. The UN estimates it will take from $50 to $120 million and from five to ten years to clear Cambodia and $30 to $40 million over seven to ten years to clear Mozambique,[14] based on a cost of between $300 to $1,000 for each mine neutralized.[15]

A. Framework for Estimating the Cost of Mineclearing Operations

Estimating the financial costs associated with demining a former war zone, be it the result of a guerrilla or conventional war, is of great interest to governments and humanitarian organizations. Off hand estimates place the cost of demining at anywhere from $300 to $1000 per mine removed. Such estimates, however, are completely inadequate for competent cost analysis and planning. Basically, the cost per mine removed is entirely the wrong measure of effectiveness of a demining program. The real issue is the cost per area of land certified as mine free. Therefore, there is always a significant cost incurred whether any mines at all are discovered and removed.

The number of mines to be removed, however, does have a secondary effect on the rate of mine clearing and ultimate costs, depending on terrain conditions and the demining technologies employed. As a result, developing more advanced demining technologies has become an additional interest within the many governments involved. Nevertheless, choosing which technologies to employ or develop in response to any one demining scenario must result from a rational cost and effectiveness model.

[13] UNOMOZ1, p. 2

[14] Landmines: A Deadly Legacy, p. 252 and Landmines in Mozambique, p. 46

[15] Ibid., p. 251

The framework for this model is presented here. It begins with a discussion of considerations surrounding the demining scenario to be costed. Following this is a presentation of the cost effectiveness of known and postulated demining technologies. A first order cost effectiveness and tradeoff analysis is made comparing the three most common demining processes and technologies. Finally, a more complete computer model has been developed to permit rapid tradeoffs between competing demining system parameters and costs.

B. Developing the Demining Scenario

It cannot be over stated that one demines a community, not simply a piece of land. The implications of this philosophy are far reaching in terms of the costs, technologies, and schedule of a demining program. The community comprises many specific locations: farms, roads, bridges, pastureorchards, paddies, buildings, houses, water sources, utilities, etc. Therefore, the environmental disturbance/damage of the clearance process should match the intended use of the specific location. This may dictate the use of different clearing processes and equipment which are most cost effective for a specific location. For example: roll roads, plow farms, probe cemeteries, sniff (dogs) houses, etc.

Some demining technologies may have more or less universal application in many specific locations. However, it is important to not destroy the long term usefulness of the location in an effort to make it mine free. For example, don't plow or flail an orchard and kill all the trees in the name of demining efficiency. As a result, the most successful demining approaches have involved the most universally applicable and basic equipment and processes.

For cost and time efficiency, the proof or level of clearance should also match the intended use of the specific location. Locations with high levels and diverse forms of human disturbance require 100% clearance to great depth of all mine and UXO threats -- roads for example. Locations with unique or low levels of human disturbance can accommodate less than 100% clearance of certain types of threats. For example, orchards, pasture, and non-mechanical farms may not require total identification and removal of heavy AT mines and large, deep UXOs, since the level of human disturbance to set these off will not be present.

However, in the long term, land use may change and the freeze-thaw cycle or erosion may cause buried objects to migrate to the surface. Under these circumstances, the local population and land owners must be educated to the residual threat, and the community must have an EOD infrastructure to deal with it. A good example is what is in place in Germany, Belgium, Holland, and Great Britain. 50 years after WWII, residual ordnance is occasionally found when land is converted to new uses, but the ordnance is successfully removed with little risk.

The development of the demining scenario should consider the entire geographical makeup of the community in question; its history and future. The technologies and processes for demining this community should as a whole address all of the components of the demining program: Survey - Detect - Verify - Neutralize - Rehabilitate. Special consideration of technologies should be made not only on their cost effectiveness face to face with the mines and UXO, but also on their training and maintenance requirements within the country in question, and their long term suitability for that country's demining infrastructure.

C. Current and Postulated Demining Technologies and Processes

1. Bounding or Surveying the Minefields

The process of surveying a country for mine and minefield locations is laborious, since precise locations have been forgotten, if ever recorded, only later to be rediscovered by accidental death or serious injury. The technologies supporting minefield surveying are the same as used in current mine clearing processes. Teams of deminers are trained in the use of metal detectors, probes, and dogs and go into the field and directly verify known or suspected mined sites.

Various levels of automation have been achieved in the use of dogs as a survey technology. One proven technique employs a vehicle, which drives along while periodically sampling the air. The air is passed through a filter which is changed at fixed intervals, the location of which is recorded on the route map. At the end of the mission, all the filters are brought back to a dog site. The dogs are presented the filters and they will cue on any one containing traces of explosives. A demining team can then more efficiently return to that specific location rather than concern themselves with the other miles of terrain the vehicle crossed. Surveying in this manner can quickly focus demining efforts over very large areas.

For most parts of the world, however, surveying is important for posting warnings and informing locals not to go into that particular area, if they do not already know. One could say that the current known reserves of minefields is sufficient to keep everyone busy clearing these for many decades. Therefore, simply identifying more minefields does not necessarily speed up the clearance process, given the current state of the demining problem.

If, however, an overfly or ground based remote sensing survey could be linked into a differential GPS register for cataloging of specific mine locations, that may be useful in speeding up demining. During the clearing process, the deminer could, hypothetically, use his own differential GPS system and walk directly up to the precise location of the mine in the data base, provided he was also sweeping for targets which the survey missed. One sees that the cost-benefit is still not so clear, since the survey may still miss some very deadly targets and the deminer must deal with these in a conventional, time consuming manner. Nevertheless, some nations are working on developing survey technologies using radar or infrared imagery to not only identify large minefields, but to also aid in pinpointed precise mine locations for more efficient clearing.

2. Detection - Verification - Neutralization of Mines and UXOs

a. Probe - Excavate - Neutralize

With proper training and experienced prodders, this is the single most safe and effective means of 100% detection and verification of a buried mine or UXO. However, it is incredibly slow and labor intensive. A prodder crouches down and pushes a probe into the ground at a shallow angle to feel if anything is buried there. If something is identified, it is then carefully uncovered or excavated. Depending on what is found, a neutralization technique is then employed. Performance parameters may be summarized as follows[7]:

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[7] FM 5-34 pg 2-4; Landmines A Deadly Legacy pg. 181, pg. 235, 241; and discussions with Hap Hambric.

1 probe every 2 seconds, with 30 minutes every excavation-neutralization.
1 probe every 2x2 inches to get all AP mines.
1 probe every 6x6 inches to get all AT mines.
One person can clear 20-50 square meters per day.
(estimate average of 4.4 square meters per man-hour)

Using this technique alone, the 200 square kilometers of estimated minefields in Cambodia could be cleared this way with current force levels (2200 prodders) in 10 years (2080 man-hrs per year).

b. Metal Detector - Probe - Excavate - Neutralize

Much faster than prodding alone, but may miss plastic and low-metallic mines.

Experienced deminers have averaged 3 to 5 km per day on poor condition gravel roads in Mozambique. These roads were cleared into the shoulder vegetation to a width of 4 meters. The deminers consisted of six 5 man teams. On an average, this works out to 66 square meters per man-hour, or about 15 times faster than prodding alone[8].

c. Bomb Detection Dog - Metal Detector - Probe - Excavate - Neutralize

Using the dogs has the advantage of getting the low-metallic mines and speeding up verification of metal detector targets. Dogs are fallible and cannot be calibrated as can a metal detector. Dogs, on an average, experience a very high success rate (95%), when the conditions are controlled. However, one cannot easily quantify their failure rate in the field (it's not simply 5%), since it is a dog and cannot tell its handler if it does not smell something and why not. This is a calibration problem. The handler can most often know if the conditions are right, but he cannot absolutely know when the conditions are wrong.

[8] Landmines in Mozambique, pg 80-83; BRDEC PAM 350-4, pg. 97.

Under the circumstances in Mozambique for example, the risk of a dog non-detection on a valid target is less than the percentage of low-metallic mines, which the metal detector is certainly going to miss out right. The area survey, however, should identify the level of threats which may be missed by whatever clearance process is selected, so that a valid risk assessment and mitigation procedure can be developed.

The dog team approach is also labor intensive, since every dog requires a dedicated handler, who only works the dog's hours. If we consider the dog-handler team to be one person, however, then the clearing rate increases to 78.6 m2 per man-hour, but with an increased man-hour cost due to the dogs. Perhaps in a cost effectiveness model, the dog should be considered an item of equipment with its associated logistics burden.

Although very effective, this process may still be too slow for many countries affected by landmines. Using this same technique in Afghanistan, a 992 man UN group of deminers, supported by 90 dogs and 2 mechanical flails is estimated to be able to clear 10 square kilometers per year. This averages as 4.8 m2 per man-hour, or about the same rate as prodding alone. The UN reports this to be a highly successful program. Nevertheless, at current UN demining team levels, Afghanistan will still take 1000 years to demine.

It is difficult to assess the efficiency discrepancies between the UN team and Ronco. It's possible the UN is going to find 16 times more mines in Afghanistan, which have to be destroyed in the same slow process. Terrain differences may have significant effects -- clearing roads versus rough, hilly land. Maybe they are going to work less than 2080 hours per year (assumed baseline). Maybe larger organizations lose efficiency. In any event, many variables not considered above can greatly affect the efficiency of any candidate demining technique.[9]

d. Automated Machinery

Combat engineering and earth moving equipment do not normally give high enough proof rates for demining. Comments made include: rollers do not conform to irregularities

[9] Landmines a Deadly Legacy pg. 147, pg. 243; FM 7-41, Mine and Tunnel Dog Training and Employment; discussions with Ronco Consulting Corp.; discussions with Rae McGrath, Mines Advisory Group; discussions with Chip Hurlock, Washington, D.C. Bomb Squad.

Plowing and Grubbing

Some terrain, soil, and land use conditions (such as farms and sandy deserts or beaches) may permit plowing or grubbing to remove mines and UXOs. If a plowing operation using a mine plow or a grubbing operation using an armored bulldozer to clear the top few inches of soil is used, additional follow-on mechanical operations are required to increase the proof rate and to rehabilitate the terrain. During the plowing and grubbing operations, the disturbed soil should be scooped up and loaded into a machine which sifts for remaining mines and UXOs which did not go off during the initial displacement.

This additional machine could be a conveyor-type which passes the soil through various levels of sieves. Remaining ordnance is then mechanically picked out and placed into a holding container or mass destruction pit. At the end of the conveyor or sieving mechanism, the clean soil or sand is loaded into scrapers or dump trucks, which then place it back where it came from.

One sees that several existing and yet to be developed armored earth movers and machines are required to support this type of clearing process. Not knowing exactly what the sifting conveyor would look like does not necessarily stop us from estimating its processing speed and cost, however.

A plowing operation may involve the following pieces of equipment and processing rates:

Plow -- 3 meters width at 3 mph = 14400 m2 per hr
6 inch depth = 2900 cubic yards per hr

Load and Sift
5 yard bucket loader -- processes 2900 cubic yards in 4 hrs

Replace soil
18 yard scraper -- places 2900 cubic yards in six inch lifts in 10 hrs

Grade surface
Grader -- grades 14,400 m2 in 2 hours

Replacing and grading sifted soil or sand could probably begin 1 hour into the plowing and sifting phase so the longest time line is 11 hours. This reduces the effective plowing rate to 1300 m2 per hour. Although it requires at least four major items of machinery and equipment, this process is 16 times faster than dogs and detectors alone.

Grubbing -- Armored bulldozer -- 1000 m2 per hour
6 inch depth = 200 cubic yards per hr

Load and Sift
5 yard bucket loader -- 200 cubic yards in .27 hours

Replace soil
18 yard scraper -- 200 cubic yards in .7 hours

Grade surface -- 1000 m2 in .12 hours.

Sifting and replacing can begin after the first bucket load is processed, so the longest time line is the total grubbing effort. This process is about 1000 m2 per hour.[10]

Summary of Clearing Rates for Current Technologies

Probe - Excavate	4.4 m2 / man-hr
Detector - Probe - Excavate	66
Dog - Detector - Probe - Excavate	78.6

Summary of Hypothetical Mechanical Technologies

Roller	24000 m2 / hour
Walker	3200
Plow - Sift - Replace	1300
Grub - Sift - Replace	1000

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[10] FM 5-333 pg 6-5; FM 5-34 pg 2-4.

e. Cost Data[11]

Expatriate western deminer (includes insurance, travel, subsistence)	$ 75 / hr
Local Deminer	$ 2 / hr
Metal Detector	$ 3,500 each
Batteries	$ 35 each
Battery Charger	$ 200 each
Tool Kit (for marking lane)	$ 150 each
Probe	$ 33 each
Grapnel with 50 meters of cord	$ 20 each
Explosives (shipped to site)	$ 3.00 / pound
Explosive primer cord	$ 0.16 / foot
Electric blasting cap (with 24 foot wire)	$ 3.50 each
Electric detonator firing unit	$ 500 each
Protective clothing	$ 150 each
Trucks (delivered to country)	$ 35,000 each

[11] Emergency Proposal for Landmine-Related Project in Angola, Mines Advisory Group; Mines a Deadly Legacy pg. 252.

Mechanical Devices[12]

road grader	$ 215,000
D-9 bulldozer	625,000
5 yard bucket loader	315,000
12 yard scraper	225,000

f. Technology Overview

Those involved in the development and application of countermine technologies may look at the demining problem slightly differently than those who have been demining in the Third World. The Third World has a tremendous resource available for demining -- people. The most cost effective approaches, all things consider, may simply involve extensive training and education in the use of the most rudimentary equipment and its associated hazards. Given enough probes, all the mines may eventually be found and cleared, although not necessarily in these people's lifetimes.

Some have stated that the number one demining problem is detecting plastic or low-metallic mines. Close investigation, however, gives the impression that those with this problem have found a workable solution. That is to use dogs. There may still be a better way, but convincing the deminers may be the biggest challenge. The reality is that the deminers must ultimately select their equipment. They select the equipment based on their experiences. The lesson here is that the technology developers have to get close with the deminers in the field if a new piece of equipment is to be successful, regardless of how well it really works.

3. Cost Effectiveness Estimates for a Baseline Scenario.

To illustrate the interaction of many process parameters on the actual cost effectiveness of demining technologies, a simple baseline scenario is developed. Given a hypothetical mined location, the following assumptions are made:

[12] commercial cost, Caterpillar Sales, Baltimore, Maryland.

Assumptions:

1. no false alarms or false alarms consistent for each process.
2. all salaries are based on local personnel ($16 per day).
3. average mine density of 4 mines per 100 square meters.
4. contour, texture, water, weather is appropriate for process.
5. closure is reached every day on all detections.

The first four assumptions are made to simplify this first order tradeoff analysis, and are self explanatory. At this point they establish a level field for evaluating various demining technologies. The assumption of closure is important to discuss in detail, however. A serious problem in the Third World is the black and gray markets in mines, ordnance, and explosives. Often, mines and ordnance which have been detected or cleared are later pilfered. The demining community seeks to avoid aggravating this trade in dangerous materials.

To this end, the demining process they employ attempts to physically destroy every dangerous item cleared or unearthed on a daily basis. Therefore, the size of each demining team, the hours they work, and their demining locations are tailored toward reaching this closure at the end of the day. In other words, every mine detected will be unearthed and will be destroyed by that evening. Clearly, within this practice, it is not useful to emphasize detection rates which are faster than neutralization rates. This consideration can greatly affect any cost analysis and the selection of appropriate demining technologies.

Process #1 Probing

Probe - Verify - Neutralize

Assumptions:

All detections are verified and neutralized when found, since the danger of accidental contact is too great to permit continued probing around a suspected target. Therefore, all suspected targets are immediately excavated and activity stops when a mine is being neutralized (grapnel pull).

each prober sweeps a 1 meter lane -- 36 m2 in 6 hours

expect 1.4 mines per lane -- 12 minutes to excavate/verify

-- 5.25 minutes to neutralize

1.4 * 17.25 = 24 minutes

total daily working time = 6.4 hours

3 lanes will clear 108 m2 per day

Staffing:

6 probers who also excavate

1 neutralizer

1 medic

1 supervisor

total 9 personnel at $ 16 per day = $ 144

Equipment:

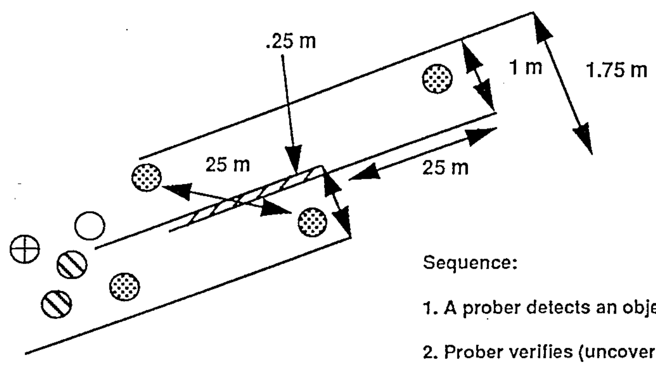
Tools, grapnels, probes	-- $0.73 per day
Backup Explosives	-- $6.60 per day

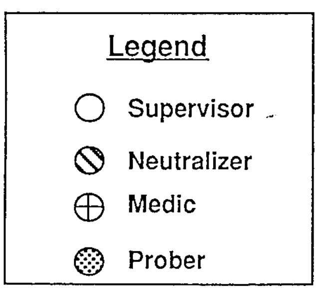
Total Daily Cost: $ 151.33

Total Cost to Clear: $ 1.40 per square meter

A significant cost to any demining operation is the use of explosives as the means of destroying landmines and ordnance. Although $3.00 per pound for a one pound block of explosives and 16 cents per foot of primer cord may not seem like much, there are an estimated 100 million landmines which need to be cleaned up world-wide. The approved procedure when using explosives is to use a one pound block per mine, and if possible connect using explosive primer cord up to five mines, provided they were all within 50 feet of each other. This speeds up the destruction process and uses only one electrical blasting cap. If all of these 100 million mines were each destroyed in situ by a block of explosives, with five blocks connected by primer cord to one electrical detonator, the cost for these explosives, the detonators, and primer cord would exceed $ 1.2 billion. Figure 7 illustrates this generic mineclearing process.

Current Techniques Elaborated (Probing Alone)





Sequence:

1. A prober detects an object
2. Prober verifies (uncovers mine) — 12 minutes
3. If mine is verified, neutralizer advances to mine and other personnel mark their positions and withdraw 50 m. If false alarm sweep continues (Other probers continue to advance 1.2 m until mine is verified.) — 1 minute/6 minutes* (walk at .83 m/sec + time to mark position.)
4. Neutralizer places grapnel or explosives — 2 minutes
5. Neutralizer withdraws 50 m and detonates explosive if grapnel is not employed — 1 minute
6. Neutralizer pulls grapnel and waits — 5 minutes
7. Mine is removed for later disposal and personnel return to positions and resume probing — 1 minute

* BRDEC Pam 350 - 4 indicates a 300 m safe distance when using explosives to destroy mines in situ

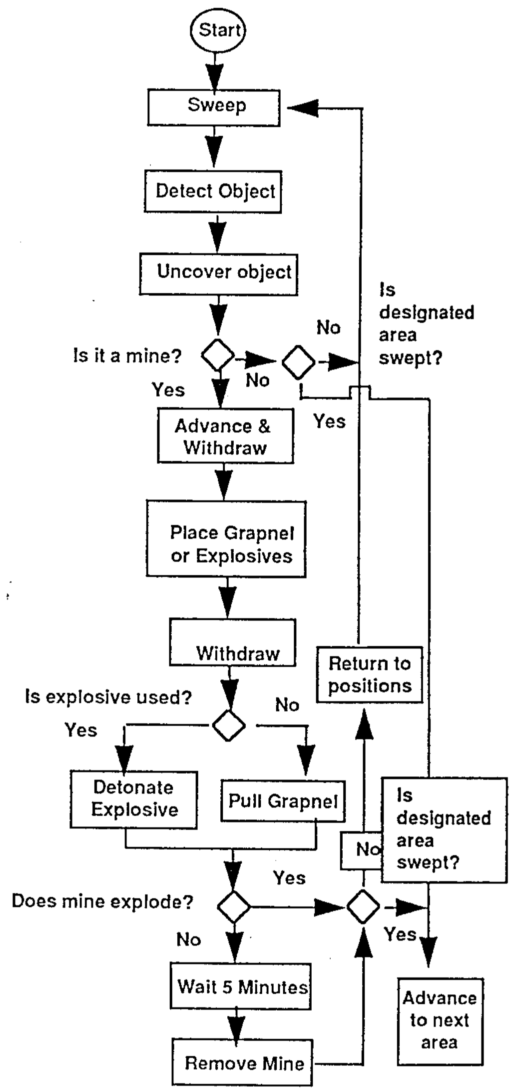


Figure 7. Probing Alone Mineclearing Process

Process #2 Metal Detector

Detect - Probe - Excavate

Assumptions:

All metal detections are immediately marked for follow-up verification by probing and excavating. Valid targets are neutralized en masse at the end of the day, since the danger of accidental contact is less when using a metal detector, which has a larger standoff than a probe. Using the grapnel pull method to dislodge the mine, 5 targets can be dealt with simultaneously. If a mine does not detonate, wait 5 minutes and then carry it to a mass destruction pit.

two detectors and markers sweep a 2.75 meter lane
-- 1700 m2 in 5 hours
during this time
-- 12 minutes to excavate/verify each target
68 mines are expected to be found
neutralize 5 at a time -- 13.6 pulls at 5.25 minutes each
= 1.19 hours to neutralize
total daily working time = 6.19 hours

Staffing:

4 detector operators
2 target markers
2 probers who also excavate
1 neutralizer
1 medic
1 supervisor

total 11 personnel at $ 16 per day = $ 176

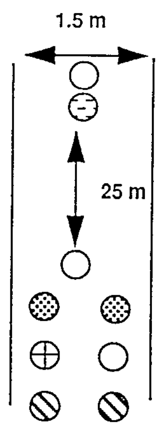
Equipment:

Tools	--	$ 11.50 per day
Backup Explosives	--	$ 104.00
4 metal detectors at $ 2.30 per day each	--	$ 9.20

Total Daily Cost -- $ 300.70

Total Cost to Clear -- $ 0.18 per square meter

Current Techniques Elaborated (Metallic Mine Detector and Probing)



Legend

- Supervisor
- Mine detector
- Marker
- Neutralizer
- Medic
- Prober

Sequence:

1. A metallic detector indicates a mine or marker finds visual indicator
2. Marker marks indication and sweep continues - negligible
3. Probers advance and verify (uncovers object) - 12 minutes

On completion of sweep of specified area, or when sweepers have advanced at least 50 m from mine ...

4. Neutralizers advance to mines and other personnel withdraw 50 m - 1 minute
5. Neutralizers place grapnel or explosives - 2 minutes
6. Neutralizers withdraw 50 m and detonate explosive if grapnel is not employed - 1 minute
7. Neutralizers pull grapnels and wait (up to 5 mines can be neutralized at a time with an A-frame, per BRDEC PAM 350-4. Theoretically, there is no limit on the number of mines that can linked and neutralized using explosive and det cord.) - 5 minutes

9. Mines are removed for later disposal - 1 minute

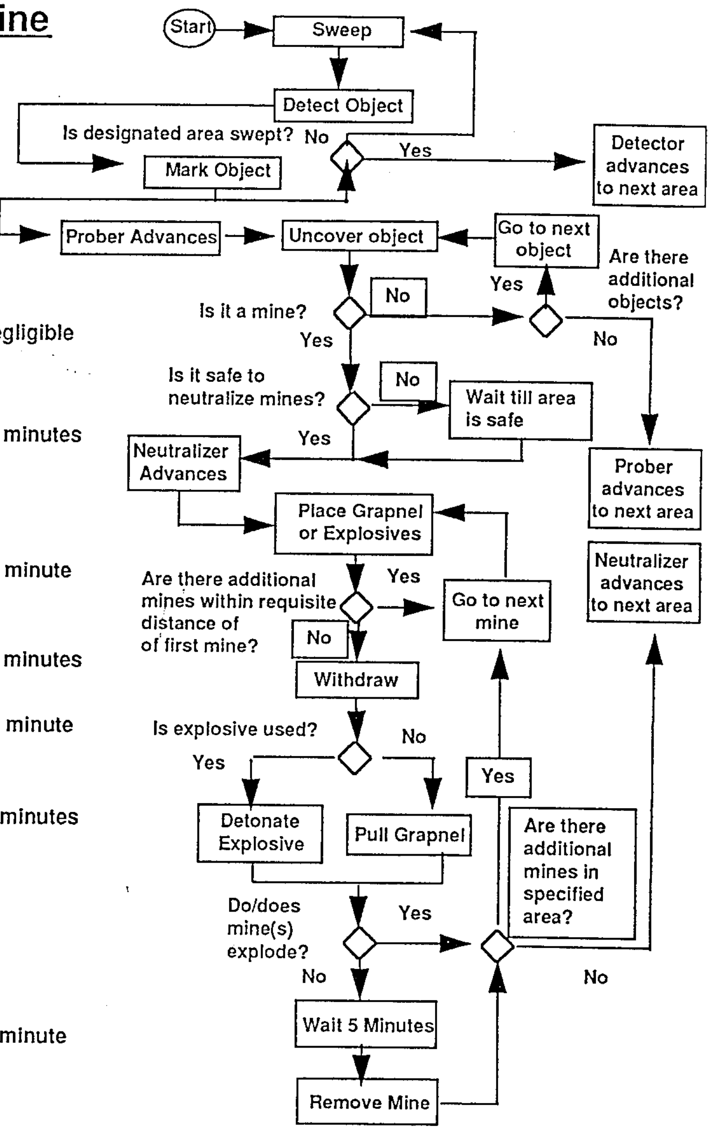


Figure 8. Metal Detector Mineclearing Process

Process #3 Dogs and Metal Detectors

Sniff - Detect - Probe - Excavate

Assumptions:

All sniffs are immediately marked for follow-up verification by metal detector, probing and excavating. Valid targets must be neutralized en masse at the end of the day, since residual odor will prevent dogs from further work if a mine is detonated. Therefore, the total area swept each day is limited to the number of mines which can be completely neutralized by the end of the day. Using the grapnel pull method to dislodge the mine, 5 targets can be dealt with simultaneously at he end of the day. If a mine does not detonate, wait 5 minutes and then carry it to a mass destruction pit.

two dog teams, detectors, and markers sweep a 3 meter lane
-- 6400 m2 in 4 hours
256 mines expected.
during this time
-- 12 minutes to excavate/verify each target
= 51.2 manhours required
= 10 excavators for 5.12 hours

neutralize 5 mines at a time in 2 safe distance zones
(each zone is 50x50 meters), each zone has a neutralizer
and supervisor
= 2.2 hours to neutralize

total daily working time = 7.32 hours

Staffing:

- 2 dogs
- 2 dog handlers
- 4 detector operators
- 2 target markers
- 10 probers who also excavate
- 2 zone neutralizers
- 2 zone supervisors
- 1 medic
- 1 top supervisor

total 26 personnel at $ 16 per day = $ 416

Equipment:

Tools	--	$ 43.20 per day
Backup Explosives	--	$ 391.00
4 metal detectors at $ 2.30 per day each	--	$ 9.20
2 dogs depreciate at $ 10 per day	--	$ 20.00

Total Daily Cost -- $ 879.40

Total Cost to Clear -- $ 0.14 per square meter

Other Processes

Figures 10 and 11 show additional mineclearing processes, equipment employed, and personnel employed.

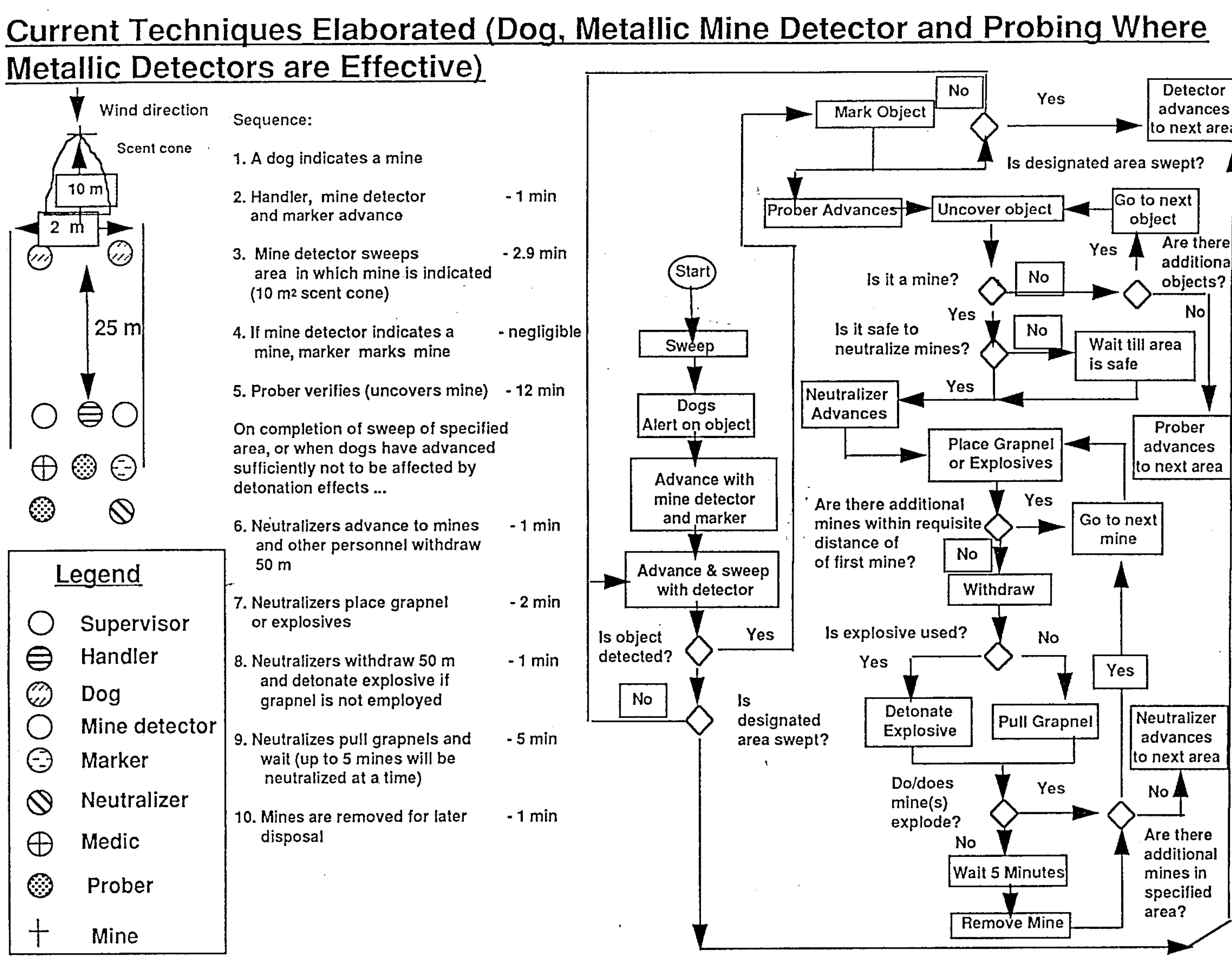
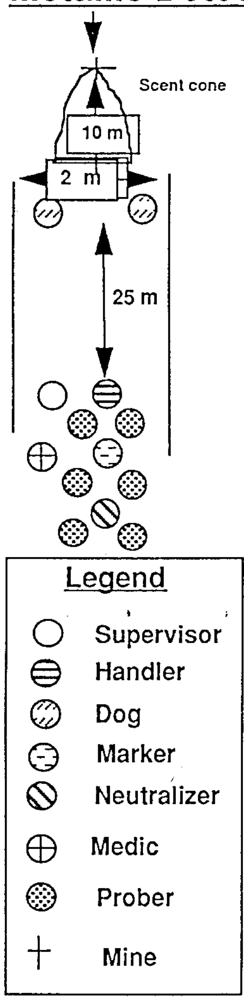


Figure 9. Dog and Metal Detector Mineclearing Process

Current Techniques Elaborated (Dog, Metallic Mine Detector and Probing Where Metallic Detectors Are Not Effective)



Sequence:

1. A dog indicates a mine
2. Handler and probers advance - 1 min
3. Probers sweep area - 1.67 hrs
4. Marker marks object - negligible
5. Prober verifies (uncovers mines) - 12 min

On completion of sweep of specified area, or when dogs have advanced sufficiently not to be affected by detonation effects ...

6. Neutralizer advances to mine and other personnel withdraw 50 m - 1 min
7. Neutralizer places grapnel or explosives - 2 min
8. Neutralizer withdraws 50 m and detonates explosive if grapnel is not employed - 1 min
9. Neutralizer pulls grapnel and waits (up to 5 mines will be neutralized at a time) - 5 min
10. Mine is removed for later disposal - 1 min

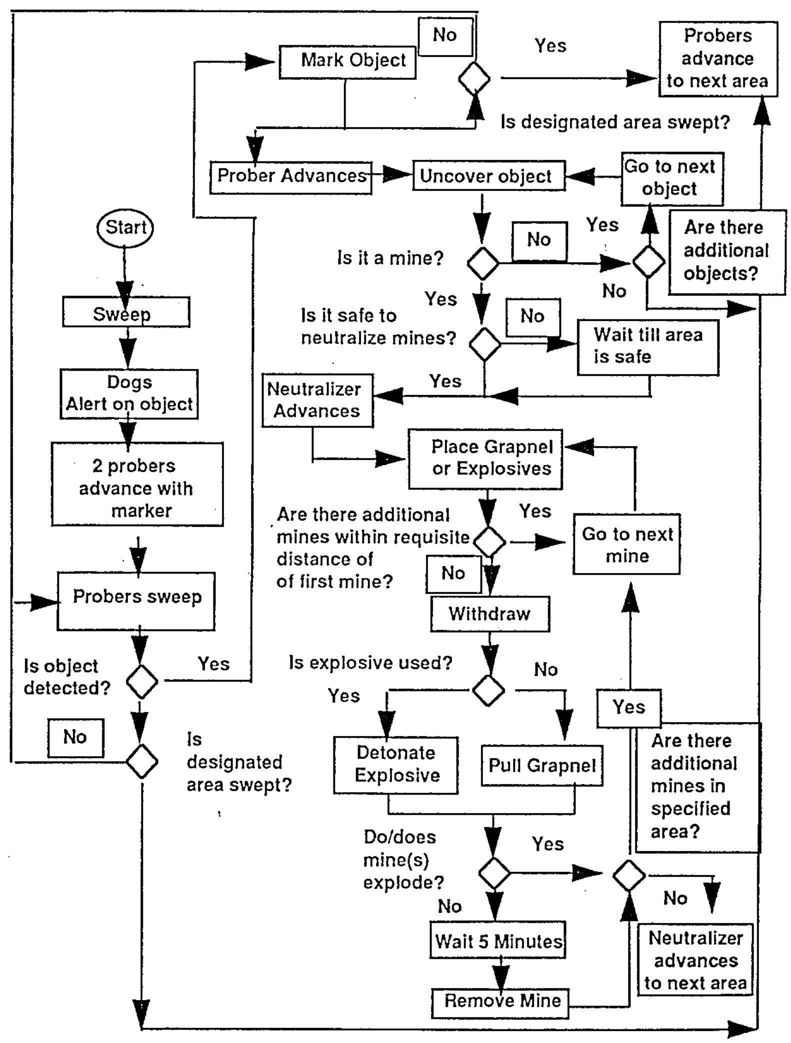
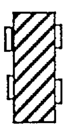


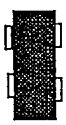
Figure 10. Dog, Metal Detector, and Probing (for plastic mines) Mineclearing Process

Current Techniques Elaborated (MDDS)

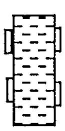
Vapor Detection
- Two man crew



Dog Team
- Two man crew
- Dog Handler
- Two dogs



Clearance
- Two man crew
- Robotic arm operator



Sequence:

1. Vapor collection indicates a mine
2. Dog and Clearance Teams move to area (assume 25 km at 50 km/hr) - .5 hrs
3. Dogs exit vehicle and localize mines (8,000 m2 / 1, 571 m2) - 5.1 hrs
4. Clearance vehicle advances (assume .5 km at 50 km/hr) - .6 min
5. Clearance vehicle detects and marks mine (assume metallic mine detector with the same sweep rate as manual detector and a scent cone of 10m2) - 2.9 min
6. Clearance vehicle withdraws - negligible
7. Sensor head is removed, excavation head is affixed to robotic arm (educated guess) - 15 min
8. Clearance vehicle returns to site - negligible
9. Clearance vehicle excavates mine (educated guess) - 5 minute
10. Clearance vehicle moves mine to edge of road for disposal - negligible
11. After 5 minutes mine is picked-up and moved to designated site for later disposal - 5 minutes

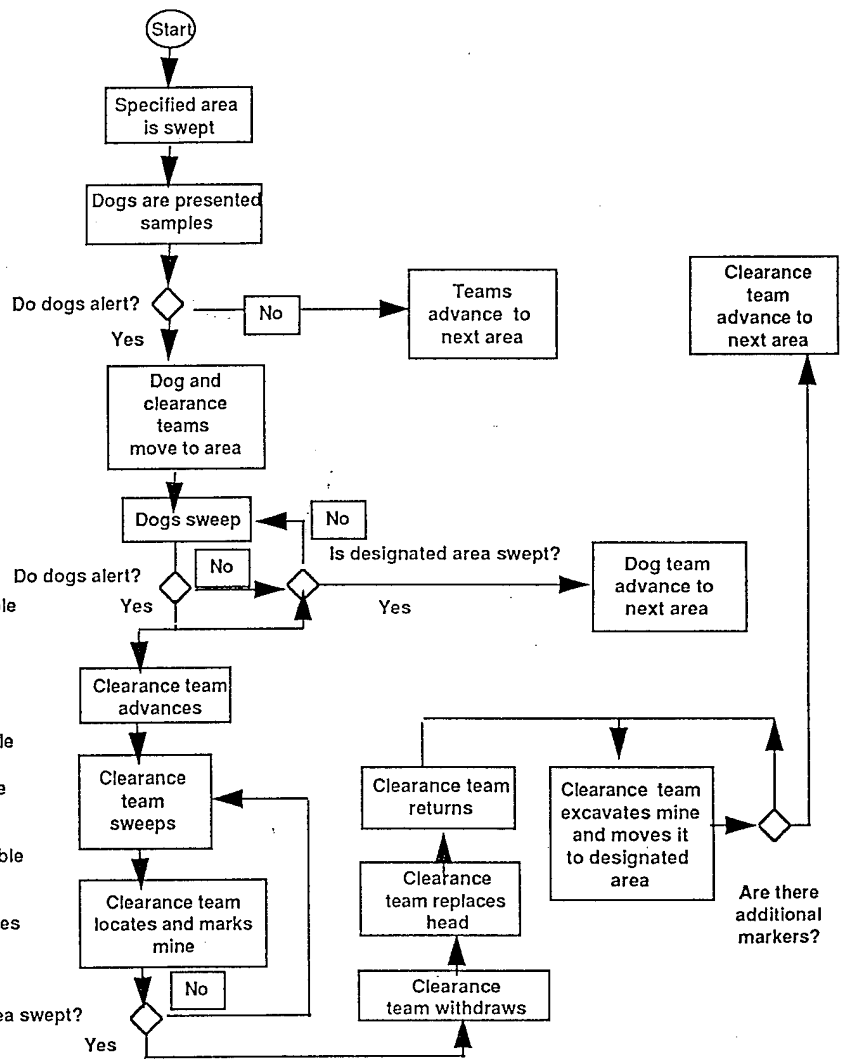


Figure 11. Mobile Dog and Robotic Mineclearing Process

4. Summary of Demining Costs

Administrative and logistics overhead for demining operations typically multiply clearance costs by 2.75 as a burdened rate to sustain the operations. These cost involve purchasing and maintaining a base camp and its equipment, training demining personnel, feeding and housing personnel, establishing radio and telephone communications, and supporting transportation within the country. Applying this burden rate to the base rate per square meter cleared shows the following cost effectiveness breakout for the three baseline demining processes:

#1	Probing	--	$ 3.85 per square meter
#2	Metal Detectors	--	$ 0.50
#3	Dogs	--	$ 0.39

Since most real world scenarios will involve conditions other than those assumed in this basic analysis, a sensitivity analysis of these result is presented. This sensitivity analysis varied the minefield density from the assumed average of 4 mines per 100 square meters. This simple variation shows dramatic cost effectiveness shifts when using these three baseline demining processes.

Sensitivity Analysis

Minefield Density per 100 m2	Process #1 Probing		Process #2 Detectors		Process #3 Dogs	
	daily area	cost factor	daily area	cost factor	daily area	cost factor
0	108	1	2040	.83	6400	1
4	108	1	1700	1	6400	1
10	108	1	1700	1	3000	2.1
20	108	1	1200	1.4	1500	4.3
30	90	1.2	900	1.9	1000	6.2
40	80	1.4	750	2.3	750	8.5

The effect of increasing minefield density is that clearing the land costs more. However, this increase is different for each technology. The cost driver is again the issue that closure must be reached at the end of each day. Therefore, one must stop detecting mines at the limit which can be destroyed by that evening.

Although the most expensive demining approach, probing is the most predictable from a cost effectiveness and planning point of view. Regardless of the number of mines in the ground, probing will cost roughly the same per square meter cleared, with the cost factor increasing over the baseline only with ridiculously dense minefields. Nevertheless, probing remains the single most expensive approach to clearing landmines, regardless of minefield density.

An interesting reversal in cost effectiveness, however, occurs between using detectors alone and detectors with dogs. At minefield densities between 4 and 10 mines per 100 square meters, at about 5.3, the use of dogs may begin to increase clearance costs. The reason for this is that dogs can very quickly indicate that mines are present, but if there are too many mines it becomes dangerous for the dogs to operate. Plus it becomes difficult for them to pinpoint the mine location. In very dense minefield, the dog can only indicate that there are mines there. Pinpointing then is turned over to the detector operators.

When there are no mines present, which often happens, either dogs or detectors provide the most cost effective approach to certifying the location as mine free. In this analysis the dogs are considered to be operating on foot so there is no cost reduction when no mines are found. The excavators and neutralizers end up having nothing to do, but must be paid any way.

When detectors are used and no mines are found, the costs are shown to decrease. However, this may only be a anomaly in the analysis. This analysis assumed that false alarms were consistent between technologies, or there were no false alarms considered. This is highly unlikely when using metal detectors. A false alarm could be considered a mine detection in this case. More than likely, detectors will be operating in an environment where several false alarms per 100 square meters exist.

Only the dogs are nearly immune to false alarms, unless intentionally spoofed. However, as discussed earlier, only a well trained dog handler can determine that the dog is indeed working as expected that day in that location. If a dog does not indicate a mine, it's not always because there is no mine. It's because the dog did not smell a mine.

The dog can also smell something that is not a real mine danger. There are ways to spoof dogs intentionally. For example, a dog will cue on finely ground explosives mixed in with the soil. The handler and detector will discover nothing, but the dog will smell explosives. However, such practice and its effect is out of the scope of this basic analysis.

V.
COMPUTER MODELING

The computer model developed to evaluate the cost effectiveness of different processes and parameters comprises four modules: 1) Scenario Development, 2) Survey, 3) Clearance, and 4) Cost Analysis. This organization to the model is consistent with the community oriented demining philosophy and incorporates the distinct elements involved in a demining program. Within the scenario development, a distribution of landmine concentrations can be postulated, which may represented the likely situation with a particular country or region. Using a flexible scenario approach in the modeling permits the survey process to be fully challenged and evaluated from a cost and effectiveness perspective. Survey outputs include the distribution mines which were identified by the survey technique, and the amount of un-mined area which will also end up being cleared, due to errors in the survey process. The results of the survey, which are now scenario dependent, are then passed on to the clearance module. Each candidate clearance process is evaluated against the survey results to determine the level of clearance achieved. Finally, the cost module calculates the total cost and duration of all survey and clearance processes considered for that scenario, based on cost and level-of-effort (LOE) input parameters.

This model is sufficiently flexible and robust to permit a multitude of survey and clearance processes -- either existing, emerging, or postulated -- to be evaluated against real world demining scenarios. For this reason, this model is useful not only for achieving the stated objectives of this study, but also as a planning and evaluation tool for ongoing and upcoming demining efforts.

1. Scenario Generation Module

The inputs for the scenario generation are shown in Table 6 for the Mozambique scenario evaluated in this study.

Table 6
Mozambique Scenario Inputs

Total area to be considered (square kilometers)	39,350
Total estimated number of mines	1,000,000
Estimated mine cluster distribution:	

% occurrence	cluster area (square meters)	# mines
5	1000	2
20	1000	5
50	1000	10
20	1000	20
5	1000	30

The rationale for entering an estimated mine cluster distribution within the country is that residual landmines are not evenly distributed throughout a war zone. Mines are typically placed in clusters, and if the clusters are large enough one may call it a minefield. In Mozambique, as in other guerrilla war zones, large minefields are rare, but may still occur. More often, however, several mines are placed in relatively close proximity around a bridge, road intersection, etc., which is heavily traveled. The estimated distribution of mine clusters can have a significant effect on surveying and clearing operations, and should be considered in the cost and effectiveness modeling. Table 6 shows our best estimate of what could be expected in Mozambique, based on reported mine clearing operations to date.

The percent occurrence in Table 6 means that this percentage of mines will occur in clusters of this many mines. For example, 5% of mines will be found in clusters containing only two mines, and these two mines will be located within an area of 1000 square meters. Depending on the estimated distribution of mines within the country, some survey techniques may have more or less effectiveness, as will be discussed in the survey module of this model.

Table 7 shows cluster distribution output for the Mozambique scenario.

Table 7
Mozambique Scenario Output

# clusters	Cluster Distribution # mines in cluster	mines per 100 square meters
25,000	2	0.20
40,000	5	0.50
50,000	10	1.00
10,000	20	2.00
1,667	30	3.00

2. Country Survey Module

Table 8a,b,c shows typical survey system inputs for the three survey technologies assessed in this study.

Table 8a
Human Intelligence (HUMINT) Survey Inputs

0.00	probability of mine detection
0.95	probability of cluster detection
0.00	number of false mine detections per square kilometer
0.33	false cluster detection area as a percentage of a square kilometer
0.00	maximum detection location error in meters
30.00	local man-hours per square kilometer surveyed
0.00	expatriate man-hours per square kilometer surveyed
8.00	work day number of hours
0.00	survey system square kilometers per hour
0.00	survey system duty cycle hours per day

Table 8b
MEDDS Survey Inputs

0.95	probability of mine detection
0.00	probability of cluster detection
0.00	number of false mine detections per square kilometer
0.00	false cluster detection area as a percentage of a square kilometer
125.00	maximum detection location error in meters
0.00	local man-hours per square kilometer surveyed
40.00	expatriate man-hours per square kilometer surveyed
8.00	work day number of hours
0.05	survey system square kilometers per hour
8.00	survey system duty cycle hours per day

Table 8c
Airborne Survey Inputs

0.70	probability of mine detection
0.00	probability of cluster detection
0.50	number of false mine detections per square kilometer
0.00	false cluster detection area as a percentage of a square kilometer
150.00	maximum detection location error in meters
0.00	local man-hours per square kilometer surveyed
0.47	expatriate man-hours per square kilometer surveyed
8.00	work day number of hours
4.30	survey system square kilometers per hour
8.00	survey system duty cycle hours per day

As shown in Tables 8a through 8c, survey technologies either detect the presence of landmines by directly detecting clusters or by detecting individual mines and then surmising the presence of a minefield cluster. For example, HUMINT is a process of interviewing local people, checking records, and looking at maps to make an educated guess as to whether a particular location should be checked for landmines. Therefore, HUMINT is not a landmine detection process, it is a cluster detection process. Detection of the cluster occurs when a correct decision is made based on relevant information concerning that location. There may or may not be any landmines in that location, but the location will be cleared by a demining team anyway. Hence, there is a large percentage of area that will be cleared that contains no mines at all -- 33% of the total area in this scenario.

Our best estimate of the percentage of landmine clusters which will be correctly identified in this scenario is 95% by HUMINT. However, this is at a cost of having to clear 33% of the total area. If we had wanted to correctly identify 100% of the clusters by HUMINT, the only option is to clear 100% of the area in question. Therefore, there is a tradeoff when using HUMINT, as to how many mines will eventually be cleared.

The MEDDS and Airborne detection systems identify landmine clusters through direct detection of an individual landmine. As a result, clusters with many mines have a higher inherent chance of being detected than low density clusters. For example, a 70% chance of identifying any one mine will result in a 70% chance of correctly finding a 1 mine cluster. The probability of finding clusters with more than one mine is correspondingly higher, since a few mines can be missed and the cluster will still be found. This illustrates the importance of estimating the mine cluster distribution within the country.

Tables 9a,b,c show the survey results for the three survey systems, based on the above inputs.

Table 9a
Survey Results for HUMINT

	Distribution of Clusters Found by Survey	
cluster size	number of clusters	percent of total
2	23,749	95
5	37,999	95
10	47,499	95
20	9,499	94.99
30	1,583	94.96

unmined area to be cleared (square kilometers)	12,985.5
local man-hours expended for survey	1,180,500
expatriate man-hours	0
survey system hours	0
survey system days	0

Table 9b
Survey Results for MEDDS

cluster size	Distribution of Clusters Found by Survey number of clusters	percent of total
2	24,937	99.75
5	39,999	100
10	49,999	100
20	10,000	100
30	1,667	100

unmined area to be cleared (square kilometers)	6214.5
local man-hours expended for survey	0
expatriate man-hours	1,574,000
survey system hours	787,000
survey system days	98,375

Table 9c
Survey Results for Airborne

cluster size	Distribution of Clusters Found by Survey number of clusters	percent of total
2	22,749	91
5	39,902	99.75
10	49,999	100
20	9,999	99.99
30	1,666	99.94

unmined area to be cleared (square kilometers)	1,390
local man-hours expended for survey	0
expatriate man-hours	18,297
survey system hours	9,151
survey system days	1,144

For each supplemental survey, the above primary survey results are then re-surveyed using the supplemental system. The results are less landmine clusters identified, but also a significant reduction in unmined area that has to be cleared. In this model, the supplemental survey throws out a previous positive detection if it is not reconfirmed by the supplemental survey. Hence, the supplemental survey should have at least as high a detection probability as the primary.

There may be other ways of handling supplemental survey information. For example, an area will be cleared if either survey indicates a positive detection. In this case, the number of clusters detected by the primary survey will not decrease as a result of a supplemental survey. However, more false alarms will be generated by the supplemental survey, so unmined area to be cleared will not decrease as much as before.

One could also do a complementary survey. This means, take the area declared unmined and not to be cleared by the primary survey, and resurvey it with the second survey process. This will also increase the number of cluster ultimately identified and cleared, but will also increase the unmined area that has to be cleared due to more false detections. So again there are tradeoffs in how one configures the survey process. These latter two survey options are not considered in this study.

3. Landmine Clearance Module

The clearance process to be used requires similar inputs in order to evaluated effectiveness and efficiency. Tables 10a, b, c, and d show the inputs used for the five clearance processes evaluated in this study.

Table 10a
Clearance Process Inputs
Probing

9	basic team size number of people
12.00	minutes to excavate and verify a suspected target detection
2	1=batch process, 2=continuous flow of excavating/verifying
0.00	area of neutralization safe zone in square meters
1	number of mines per simultaneous neutralization
1	number of mines per simultaneous excavation/verify
5.25	minutes to neutralize a mine
8.00	work day hours
3.00	false alarms per 100 square meters
1.00	probability of true mine detection
6.00	basic team sweep rate (no false alarms and no true detections) square meters per hour

Table 10b
Clearance Process Inputs
Detectors

11	basic team size number of people
12.00	minutes to excavate and verify a suspected target detection
1	1=batch process, 2=continuous flow of excavating/verifying
2500	area of neutralization safe zone in square meters
5	number of mines per simultaneous neutralization
2	number of mines per simultaneous excavation/verify
5.25	minutes to neutralize a mine
8.00	work day hours
3.00	false alarms per 100 square meters
0.92	probability of true mine detection
340	basic team sweep rate (no false alarms and no true detections) square meters per hour

Table 10c
Clearance Process Inputs
Dogs and Detectors

26	basic team size number of people
12.00	minutes to excavate and verify a suspected target detection
1	1=batch process, 2=continuous flow of excavating/verifying
2500	area of neutralization safe zone in square meters
5	number of mines per simultaneous neutralization
10	number of mines per simultaneous excavation/verify
5.25	minutes to neutralize a mine
8.00	work day hours
3.00	false alarms per 100 square meters
0.95	probability of true mine detection
1600	basic team sweep rate (no false alarms and no true detections) square meters per hour

Table 10d
Clearance Process Inputs
Dogs and Probing

40	basic team size number of people
12.00	minutes to excavate and verify a suspected target detection
1	1=batch process, 2=continuous flow of excavating/verifying
2500	area of neutralization safe zone in square meters
5	number of mines per simultaneous neutralization
3	number of mines per simultaneous excavation/verify
5.25	minutes to neutralize a mine
8.00	work day hours
3.00	false alarms per 100 square meters
0.95	probability of true mine detection
1600	basic team sweep rate (no false alarms and no true detections) square meters per hour

The development of these inputs requires considerable preparatory work and analysis on how best to employ different demining technologies. The costs involved in clearance operations are more complicated than just counting the number of people working and measuring the area covered each day. To evaluate efficiency, individual jobs, duty cycles, and task efficiencies have to be considered in relation to the minefield cluster parameters.

As shown in the inputs tables, clearance operations are structured around a basic clearance team. Team size varies based on the clearance technique and the safe zone area within which each team may operate independently from another team. Teams which are bigger will normally be covering more area. For example, 26 men support only two dogs in the Dogs and Detectors process. This is because the dogs can very rapidly locate suspected mine sights to within ten meters. However, detector operators work much slower when pinpointing the exact location to be excavated. Therefore, this technology employs a basic team which is much large than a probing alone team, but it can cover more area in a day's work. Even more personnel support in the form of probers is needed when the detectors are unsafe to use, as in a minefield situation which includes plastic or low-metallic landmines. Each team also employs a proportional number of support personnel, such as medics and supervisors.

An important aspect of demining operations is that all mines detected in a work day must be neutralized by the end of the day, in order to avoid pilferage. Therefore, the actual amount of area cleared will be affected by the false alarm and true detection rates of the clearance technique. The basic sweep rate of a team is based on no detections or false alarms. However, as each false alarms is marked and excavated, time is lost. Similarly, each true detection, excavation, and neutralization costs more time than a false alarm. Therefore, for each cluster density and the system false alarms rate, the model calculates the maximum area which can be swept and neutralized each work day.

Some clearance processes can be characterized as batch processes or continuous flow processes. Making this distinction also affects process and team efficiency. Probing alone is a continuous flow process, since each time a detection (false or true) is made the target has to be excavated and neutralized (if true) before that prober can continue on. It is simply too dangerous for a prober to continue to probe on after making a suspected contact.

Conversely, some processes can be characterized as batch clearance processes. Dog teams and metal detector teams can more rapidly sweep and area with less risk of accidentally detonating a suspected target. The dog will immediately sit at the edge of the target sent cone, and will perhaps never actually step on a mine that it does not smell. Similarly, a metal detector operator does not step on every square inch of terrain as he sweeps his detector. Therefore, using a dog or detector system permits the operator to continue sweeping as another individual marks the suspected target, to be followed by another individual who may begin excavation of that target once the dog or detector team has moved safely ahead. After all suspected targets are excavated and verified, bulk or batch neutralization can then occur. When structuring a batch process clearance team, the number of excavators and neutralizers has to be carefully balanced with the number of dog teams or detector teams, based on suspects false alarm and true detection rates.

Structuring the clearance process inputs to this level of detail permits tradeoffs and optimization of demining teams to be performed, as well as evaluating the efficiency of current team structure.

For each survey process, the resulting landmine cluster distribution which has been identified by the survey is then cleared according to these input parameters. The clearance process outputs are the total number of mines cleared and the number of team days to perform the clearance of all unmined and mined areas identified in the survey.

4. Survey and Clearance Cost Module

Each survey and clearance process requires specific cost inputs in order to assess the total cost of operations. Since operations costs can vary depending on the length of the demining program, the level of effort must also be entered. For this Mozambique scenario, all survey and demining team levels of effort were adjusted so that each technology combination required ten years to complete. Surveying is assumed to be able to run concurrently with clearing, with a negligible time delay before the first clearance assignments. Therefore, both survey and clearance operations are staffed for ten years of work. Where survey systems are very efficient, such as with the airborne technology, only one survey team may be required, and they may complete work in less than ten years. However, one cannot field less than one whole team under these circumstances. Survey system and logistics daily costs are based on the purchase price of equipment amortized over a life cycle of 10 years. The following tables present the primary survey and clearance cost and level of effort inputs. Level of efforts for supplemental surveys vary, as will the clearance team levels of effort. Cost inputs are constant, however. There are a total of 24 clearance process levels of effort for a total of 6 survey processes. A representative sample is provided here.

Table 11a
Survey System Cost Inputs
HUMINT

16	survey local personnel daily rate in dollars
300	survey expatriate personnel daily rate
0	survey system daily rate
3000	total training cost each person
12	daily logistics cost per man
50	local personnel level of effort in survey (# men)
0	expatriate level of effort
0	survey system level of effort (# systems)

Table 11b
Survey System Cost Inputs
MEDDS

0	survey local personnel daily rate in dollars
300	survey expatriate personnel daily rate
160	survey system daily rate
3000	total training cost each person
12	daily logistics cost per man
0	local personnel level of effort in survey (# men)
160	expatriate level of effort
40	survey system level of effort (# systems)

Table 11c
Survey System Cost Inputs
Airborne

0	survey local personnel daily rate in dollars
300	survey expatriate personnel daily rate
2500	survey system daily rate
3000	total training cost each person
12	daily logistics cost per man
0	local personnel level of effort in survey (# men)
4	expatriate level of effort
1	survey system level of effort (# systems)

Table 11a
Clearance System Cost Inputs
Probing

25.4	backup explosives cost per mine neutralization $
3.50	explosives cost per batch or individual neutralization $
16	daily rate for local personnel $/day
300	daily rate for expatriate personnel $/day
1.75	equipment daily cost $/day
3000	training cost per man $
12	logistics daily cost per man $/day
12,128	# of basic teams Level of Effort
0	number of expatriate in a team

Table 11b
Clearance System Cost Inputs
Detectors

25.4	backup explosives cost per mine neutralization $
3.50	explosives cost per batch or individual neutralization $
16	daily rate for local personnel $/day
300	daily rate for expatriate personnel $/day
20	equipment daily cost $/day
3000	training cost per man $
12	logistics daily cost per man $/day
292	# of basic teams Level of Effort
0	number of expatriate in a team

Table 11c
Clearance System Cost Inputs
Dogs and Detectors

25.4	backup explosives cost per mine neutralization $
3.50	explosives cost per batch or individual neutralization $
16	daily rate for local personnel $/day
300	daily rate for expatriate personnel $/day
75	equipment daily cost $/day
3000	training cost per man $
12	logistics daily cost per man $/day
62	# of basic teams Level of Effort
0	number of expatriate in a team

Table 11d
Clearance System Cost Inputs
Dogs and Probing

25.4	backup explosives cost per mine neutralization $
3.50	explosives cost per batch or individual neutralization $
16	daily rate for local personnel $/day
300	daily rate for expatriate personnel $/day
65	equipment daily cost $/day
3000	training cost per man $
12	logistics daily cost per man $/day
195	# of basic teams Level of Effort
0	number of expatriate in a team

5. Casualty Modeling

Casualty assessment is performed as a straight probability depending on the clearance process and the number of mines to be cleared. Casualty information to any level of statistical confidence is not available. The most comprehensive casualty information that we have found was made available by Navy Explosive Ordnance Disposal personnel located at Indian Head, Maryland. They performed a casualty rate retrospective for handling unexploded ordnance in an attempt to quantify expected risks for future range cleanup operations. Their conclusions were that there exist too many types of explosive ordnance and too many possible dud failure conditions to provide any statistical confidence in likely handling risks. At most they could say that the risk of handling a dud munition ran from one detonation in one thousand to one in one hundred thousand.

For our purposes, we selected the higher risk end of their zone of probability. Therefore, for each mine neutralized, we assessed a probability of a casualty at one in one thousand. This casualty rate affects those deminers who neutralize a true mine target. The exception to this casualty rate for neutralizers is when using the clearance process of probing alone. Since in our Mozambique scenario, there are only one million mines to be cleared, but nearly one million deminers are required on a continuous basis, experience among the neutralizers in dealing with a live mine will be very low. Most neutralizers may not even encounter one live mine during the ten year demining project. That makes for a lot of false alarms and perhaps a lessening of care when probing and excavating a suspected target. We feel this will result in much greater risk to the deminer. For this reason, casualty rates for neutralizers when probing alone is used are assessed at one in one hundred mines encountered.

The casualty rate for a prober, if he is not the individual who then excavates and verifies the target, is assessed at one in one thousand mines detected. Probers used in this manner have the opportunity to turn a suspected target over to an excavator for verification, and the prober may perhaps retain a higher level of caution. The tradeoff here is whether to shift the burden of verification to someone other than the prober, and who will become more careless as a result. Our feeling is than someone will become careless as a result of excavating or probing numerous false alarms over the years. Either the prober or the excavator should be assessed a higher casualty rate. Our choice is the latter individual.

Assessing the casualty rate for a detector operator is more difficult than a prober, since the detector operator does not normally step upon every square inch of terrain. Therefore, there is the chance that he will not detect a target, and still not step upon it. We estimated that on an average, a detector operator will step upon 5% of the area of the minefield he is sweeping. In our Mozambique scenario, 8% of the mines are undetectable. This gives a combined probability of the detector operator stepping on an undetected mine as four in one thousand mines.

When using dogs as the detection method, the dogs are also estimated to step upon 5% of the terrain they are sweeping. However, unless the dog handler is using the dog during conditions where the dog cannot smell any explosives at all, the likelihood of the dog not smelling a mine which passes right under its nose and paws as it advances is practically zero. We estimate that the probability of the dog being employed during inappropriate conditions at one in one thousand mines encountered. This coupled with a 5% chance of stepping on it gives a casualty rate of fifty dogs in one million mines encountered. However, lacking statistical information, almost any number could be justified in these casualty rates. We have selected casualty rates which seem plausible.

Recently published research performed on behalf of the United Nations seems to support our casualty estimates, based on large scale demining operations. According to their report, a 50-fold increase in mineclearing capacity by the year 2000 to respond to the number of mines being laid annually would probably result in about 2,000 de-miners injured or killed each year.[13] Such a large increase in demining operations above current

[13] United Nations, Department of Humanitarian Affairs, "New Technologies in Mine and Minefield Detection and Mine Clearance," background paper Summary, Expert Panel (E), International Meeting on Mine Clearance, 5-7 July 1995,1.

levels would approach our hypothetical Mozambique scenario. Our modeling results estimate between approximately 2,000 to 10,000 casualties over a ten year demining program depending on the technology employed. Our casualty estimates are within the same range as those of the United Nations.

6. Cost and Operational Effectiveness Analysis Results

The following two spread sheets summarize the cost and effectiveness results for each technology approach for the Mozambique scenario.

TABLE 12A.
Demining Technology Analysis Results for a Mozambique Scenario: Process Costs

Sheet1

survey type	clearance type	detection probability	% mines surveyed	% cleared by detection	unmined area km2	survey cost $	clearance costs $	total costs $	survey $/km2	clearance $/km2	total cost/area $/km2	survey $ cost/mine	clearance $ cost/mine	total $ cost/mine
Humint			95.00		13,000	4.1 million			104			4.32		
	probing	0.999		94.9			71.3 billion	71.3 billion		1.81 million	1.81 million		75,132	75,136
	detectors	0.92		87.4			1.7 billion	1.70 billion		0.43 million	0.43 million		1,945	1,949
	dogs & detectors	0.95		90.2			875 million	879 million		22,000	22,100		1,001	1,006
	dogs & probing	0.95		90.2			4.03 billion	4.04 billion		0.102 million	0.102 million		4,610	4,624
MEDDS			99.99		6,215	75 million			1906			75		
	probing	0.999		99.9			34 billion	34.07 billion		0.86 million	.862 million		34,034	34,109
	detectors	0.92		92			859 million	934 million		22,000	24,000		934	1015
	dogs & detectors	0.95		95			453 million	528 million		12,000	14,000		477	556
	dogs & probing	0.95		95			2.04 billion	2.12 billion		54,040	56,212		2,148	2,232
airborne			99.5		1,391	3.6 million			91.5			3.6		
	probing	0.999		99.4			7.76 billion	7.764 billion		0.92 million	0.92 million		7,807	7,811
	detectors	0.92		91.5			264 million	268 million		7,000	7,100		289	293
	dogs & detectors	0.95		94.5			150 million	154 million		4,000	4,100		159	163
	dogs & probing	0.95		94.5			606 million	610 million		16,160	16,240		642	646
Humint-MEDDS			94.99		5,904	29 million			737			29		
	probing	0.999		94.9			32.5 billion	32.53 billion		0.83 million	0.831 million		34,247	34,278
	detectors	0.92		87.4			816 million	845 million		21,000	22,000		934	967
	dogs & detectors	0.95		90.2			431 million	460 million		11,000	12,000		478	510
	dogs & probing	0.95		90.2			1.94 billion	1.97 billion		49,500	51,400		2,152	2,184
Humint-airborne			94.92		459	5.3 million			135			5.3		
	probing	0.999		94.4			2.65 billion	2.655 billion		70,000	70,132		2,807	2,813
	detectors	0.92		87			145 million	150 million		4,000	4,100		167	172
	dogs & detectors	0.95		89.8			88.6 million	93.9 million		2,300	2,400		99	105
	dogs & probing	0.95		89.8			320 million	325 million		8,132	8,259		358	363
MEDDS-airborne			99.49		220	75.8 million			1926			75.8		
	probing	0.999		99.4			1.35 billion	1.42 billion		34,000	36,000		1,358	1,428
	detectors	0.92		91.5			120 million	196 million		3,000	5,000		131	214
	dogs & detectors	0.95		94.5			76.7 million	153 million		2,000	4,000		81	162
	dogs & probing	0.95		94.5			259 million	335 million		6,600	8,500		274	355

TABLE 12B.
Demining Technology Analysis Results for a Mozambique Scenario: Process Effectiveness

Sheet1

survey type	clearance type	detection probability	% mines surveyed	% cleared by detection	# people continuous LOE	#people continuous LOE	# systems continuous LOE	# systems continuous LOE	casualty probability (detection)	casualty probability (neutralization)	casualties people	casualties systems	undetected mines remaining
Humint			95.00		55		0						
	probing	0.999		94.9		1.011 million		0	0.001 prober	0.01	10,440	0	50,000
	detectors	0.92		87.4		22,330		0	0.004 detector	0.001	4,674	0	122,200
	dogs & detectors	0.95		90.2		11,024		848 dogs	0.00005 dog	0.001	4,654	48 dogs	94,152
	dogs & probing	0.95		90.2		54,080		2704 dogs	0.00005 dog	0.001	1,804	48 dogs	97,050
MEDDS			99.99		160		40						
	probing	0.999		99.9		484,632		0	0.001 prober	0.01	10,990	0	100
	detectors	0.92		92		11,209		0	0.004 detector	0.001	4,920	0	76,000
	dogs & detectors	0.95		95		5,538		426 dogs	0.00005 dog	0.001	4,900	50 dogs	46,000
	dogs & probing	0.95		95		27,040		1,352 dogs	0.00005 dog	0.001	1,900	50 dogs	49,000
airborne			99.5		4		1						
	probing	0.999		99.4		109,152		0	0.001 prober	0.01	10,935	0	5,000
	detectors	0.92		91.5		3,212		0	0.004 detector	0.001	4,895	0	81,020
	dogs & detectors	0.95		94.5		1,612		124 dogs	0.00005 dog	0.001	4,875	50 dogs	51,020
	dogs & probing	0.95		94.5		7,800		390 dogs	0.00005 dog	0.001	1,940	50 dogs	53,955
Humint-MEDDS			94.99		107		13						
	probing	0.999		94.9		458,739		0	0.001 prober	0.01	10,440	0	50,100
	detectors	0.92		87.4		10,659		0	0.004 detector	0.001	4,674	0	122,200
	dogs & detectors	0.95		90.2		5,226		402 dogs	0.00005 dog	0.001	4,655	47 dogs	94,200
	dogs & probing	0.95		90.2		25,840		1,292 dogs	0.00005 dog	0.001	1,805	47 dogs	97,050
Humint-airborne			94.92		59		1						
	probing	0.999		94.4		37,296		0	0.001 prober	0.01	10,390	0	50,800
	detectors	0.92		87		1,639		0	0.004 detector	0.001	4,667	0	126,203
	dogs & detectors	0.95		89.8		858		66 dogs	0.00005 dog	0.001	4,648	47 dogs	98,203
	dogs & probing	0.95		89.8		4,000		200 dogs	0.00005 dog	0.001	1,800	47 dogs	101,051
MEDDS-airborne			99.49		164		40 MEDDS+1 air.						
	probing	0.999		99.4		18,648		0	0.001 prober	0.01	10,935	0	5,100
	detectors	0.92		91.5		1,298		0	0.004 detector	0.001	4,895	0	81,020
	dogs & detectors	0.95		94.5		676		52 dogs	0.00005 dog	0.001	4,875	50 dogs	51,020
	dogs & probing	0.95		94.5		3,160		158 dogs	0.00005 dog	0.001	1,890	50 dogs	54,005

7. Conclusions

1. Significant demining cost reductions are achievable by employing more advanced survey technologies. This results primarily from the great reduction in un-mined area which must be checked for mines, due to survey inaccuracies.

2. Survey inaccuracies, even with detection rates in the mid to high 90th percentile, result in large numbers of remaining undetected landmines. Short of sending bomb dogs (MEDDS) throughout the entire inhabited country, most survey technologies fail to ensure very high clearance rates.

3. Probing alone effectively clears every mine and minefield identified by the country survey (99.9% proof rate), and if dogs (MEDDS) is used as the survey process, 99.9% of all mines will be cleared. However, this is achieved at an enormous human and financial cost.

4. If all mines were detectable my metal detectors, the dog-detector clearance process is the most cost effective technology for achieving nearly a 95% proof rate.

5. In the presence of plastic and low-metallic mines, the reliance on metal detectors presents a serious casualty risk. Under these circumstances, probing must be employed, with the resulting decrease in efficiency and increase in clearance costs. The dogs-probing process more than doubles costs over dogs-detectors when using the most efficient survey process (MEDDS-airborne). For other survey processes, clearance costs increase dramatically.

6. Supplemental surveys will not increase the number of mines detected by the survey. However, large clearance cost reductions are obtainable by using a supplemental survey, if leaving slightly more undetected and uncleared mines is acceptable.

7. Although survey costs are relatively small compared to clearance costs, the accuracy of the survey process has the greatest impact on total clearance costs. This tradeoff highlights the need of the survey process to minimize the amount of un-mined area that must be cleared due to survey inaccuracies.

8. Recommendations

1. Develop rapid remote sensing survey processes with effectiveness well beyond the limited capabilities of human intelligence. Multi-spectrum airborne detection systems may offer promising emerging technology. An effective near term survey process should include the use of bomb dogs.

2. Develop an effective plastic and low-metallic mine detector system, which also detects conventional metallic mines. The availability of such a device will greatly reduce demining casualties, while boosting clearance efficiency at greatly reduced cost. A near term approach to this problem may involve performing more in-depth characterization of the effectiveness of bomb dogs, and developing knowledge on when dogs cannot detect mines, and how to improve the pinpoint accuracy of a dog detection.

9. Summary

Land which must be demined quickly becomes very expensive real estate. Even using dogs, in the most ideal of conditions, it will cost 39 cents a square meter to certify as clear of mines. To put that in perspective, there are 4047 square meters in an acre of land. That land, demined, just increased in cost by $1500. There are few places where agricultural land commands any where near that value, and certainly not in the Third World.

Imagine if it had to be prodded. Its cost increased by a staggering $15,000 an acre. Few industrialized countries have land values, which even when developed or used commercially, cost that much, and only in high density urban areas.

Nevertheless, this is the only land these people have. For the most part, if the land is safe, these people are largely self-sufficient. In this respect, their land has immeasurable value according to their standards. If their land is mined, these people become refugees. At which time the rest of us begin to pay the value of that land according to our standards, and it's not cheap.

This cost effectiveness analysis framework presented here is a rational approach to assessing the utility of demining technologies and processes during both demining operations and planning phases of a project. Not all tradeoff parameters have been addressed. However, the examples shown provide a guideline for developing tradeoff analyses tailored to specific requirements and conditions, of which regional experts will have the most detailed information. Nevertheless, employing an analytical approach such as this one helps to present the demining challenge in a structure which can be understood by people with diverse backgrounds, expertise, and interests. Hopefully, more efficient and effective demining programs will result which utilize their funding resources to maximum potential.

APPENDIX A
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Ray Salamy, USAF, Andrews AFB, bomb dog team

Andy Pedersen, Naval Explosives Ordnance Disposal Center

Cheryl Parker, Explosives Technologies International

Laruie Fisher, American Red Cross

APPENDIX B
COMPUTER MODEL SOURCE CODE LISTING
AND SAMPLE INPUT/OUTPUT

```
$debug
c       demining.for            as of 7/14/95
c
c       demining main routine with 4 modules
c       module 1        scenario development
c       module 2        survey
c       module 3        demining
c       module 4        costs
c
c       scenario development
        common/inscene/atotal,mtotal,cluster(5,3)
c       atotal          total area km^2
c       mtotal          total number of mines
c       cluster         cluster distribution %,area,number
c
        common/outscene/ncluster(5)
c       ncluster        number of each cluster
c
c       survey process
        common/insurvey/surname(6,6),pdm(6,6),pdc(6,6),fmd(6,6),fcd(6,6)
     & ,al(6,6),hrlman(6,6),hrxman(6,6),dayhr(6,6),aperhr(6,6),dcyc(6,6)
        character*30 surname
c       surname         primary, secondary survey name
c       pdm             probability mine detection
c       pdc             probability cluster detection
c       fmd             false mine detection per km^2
c       fcd             false cluster detection % of a km^2
c       al              maximum location error meters
c       hrlman          local manhours per km^2 of survey
c       hrxman          expatriate manhours per km^2 of survey
c       dayhr           work day number of hours
c       aperhr          survey system km^2 per hour
c       dcyc            system duty cycle hours per day
c
        common/outsurvey/aunm(6,6),hrlms(6,6),hrxms(6,6),hrsyss(6,6),
     &  daysur(6,6),mcluster(6,6,5)
c       aunm            unmined area to be cleared
c       hrlms           total local manhours in survey
c       hrxms           total expatriate manhours in survey
c       hrsyss          total system hours in survey
c       daysur          total number of days in survey
c       mcluster        distribution of clusters found by survey
c
c       demining process
        common/indemine/dename(10),nteam(10),tex(10),ntype(10),safe(10),
     &  nsime(10,2),tneut(10),workhr(10),fal(10),pd(10),srate(10)
        character*30 dename
c       dename          demining process name
c       nteam           basic team size number of people
c       tex             minutes to excavate/verify a target
c       ntype           neutralization type - 1,batch 2,continuous
c       safe            neutralization safe zone area m^2
c       nsime ,1        number of mines per simultaneous neutralization
c             ,2        number of detections sumultaneously excavated
c       tneut           minutes for each neutralization
c       workhr          work day hours
c       fal             false alarms per 100 m^2
c       pd              probability of mine detection
c       srate           basic team sweep rate m^2/hr
c
        common/outdemine/nmines(10,6,6),nbatch(10,6,6),teamdays(10,6,6)
c       nmines          number of mines neutralized, per survey
c       nbatch          number of batch neutralizations
c       teamdays        number of team days to clear surveyed area
c
c       cost analysis
        common/inc1/scl(6,6),scx(6,6),scsys(6,6),sctr(6,6),sclog(6,6),
     &  loesl(6,6),loesx(6,6),loessys(6,6)
c       scl             survey daily cost for local person
c       scx             survey daily cost for expatriate
c       scsys           survey daily cost for system
c       sctr            survey cost to train each person
c       sclog           survey daily logistics cost per man
c       loesl           survey level of effort (# men) local
c       loesx           survey LOE expatriate
c       loessys         survey LOE # of systems
c
        common/inc2/dcl(10),dcx(10),dcsys(10),dctr(10),dclog(10),
     &  loed(10),ndx(10),dcexpl(10),dcadd(10)
c       dcexpl          demine explosive neutralization cost per mine
c       dcadd           demine additional cost per batch
c       dcl             demine daily cost for local person
c       dcx             demine daily cost for expatriate
c       dcsys           demine daily cost for system
c       dctr            demine cost to train each person
c       dclog           demine daily logistics cost per man
c       loed            demine level of effort # of basic teams
c       ndx             demine number of expatriates in basic team
c
        open (2,file='demine.out')
        write (2,*)  '                  cost and effectiveness model'
        write (2,*)  '                    for demining operations'
        write (2,*)
```

```
      write (*,*)  '                    cost and effectiveness model'
      write (*,*)  '                      for demining operations'
      write (*,*)

      call scenario
      call survey
      call clear
      call costs

      end


      subroutine scenario
c     scenario development
      common/inscene/atotal,mtotal,cluster(5,3)
c     atotal          total area km^2
c     mtotal          total number of mines
c     cluster         cluster distribution %,area,number
c
      common/outscene/ncluster(5)
c     ncluster        number of each cluster
c
      open (1,file='scene.in')
      read (1,*) atotal
      read (1,*) mtotal

      do 10 i=1,5
10    read (1,*) k,cluster(i,1),cluster(i,2),cluster(i,3)

      close (1)

      do 50 k=1,2
      if (k.eq.1) n=2
      if (k.eq.2) n=0
      write (n,*) '                    scenario input'
      write (n,*)
      write (n,*) 'total area to be considered km^2 ',atotal
      write (n,*) 'total estimated number of mines ',mtotal
      write (n,*) 'estimated mine cluster distribution:'
      write (n,*) '      % occur.          area m^2       # mines'
11    format (3f15.0)

      do 12 i=1,5
12    write (n,11) cluster(i,1),cluster(i,2),cluster(i,3)
      write (n,*)

50    continue

c     calculate number of each cluster based on distribution
c     and total number of mines
c
      do 100 i=1,5
      ncluster(i)=nint(mtotal*cluster(i,1)/100./cluster(i,3))
100   continue

      do 200 k=1,2
      if (k.eq.1) n=2
      if (k.eq.2) n=0
      write (n,*) '                   scenario structure'
      write (n,*)
      write (n,*) '                   number of clusters'
      write (n,*) '          #           # mines    # mines / 100m^2'
69    format (i15,2f15.2)

      do 70 i=1,5
      density=cluster(i,3)/cluster(i,2)*100.
70    write (n,69) ncluster(i),cluster(i,3),density
      write (n,*)

200   continue

      return
      end


      subroutine survey
c     survey process
      common/outscene/ncluster(5)
      common/inscene/atotal,mtotal,cluster(5,3)
      common/insurvey/surname(6,6),pdm(6,6),pdc(6,6),fmd(6,6),fcd(6,6)
     & ,al(6,6),hrlman(6,6),hrxman(6,6),dayhr(6,6),aperhr(6,6),dcyc(6,6)
      character*30 surname
c     surname         primary, secondary survey name
c     pdm             probability mine detection
c     pdc             probability cluster detection
c     fmd             false mine detection per km^2
c     fcd             false cluster detection % of a km^2
c     al              maximum location error meters
c     hrlman          local manhours per km^2 of survey
c     hrxman          expatriate manhours per km^2 of survey
c     dayhr           work day number of hours
c     aperhr          survey system km^2 per hour
c     dcyc            system duty cycle hours per day
```

```
c
      common/outsurvey/aunm(6,6),hrlms(6,6),hrxms(6,6),hrsyss(6,6),
     & daysur(6,6),mcluster(6,6,5)
c     aunm           unmined area to be cleared
c     hrlms          total local manhours in survey
c     hrxms          total expatriate manhours in survey
c     hrsyss         total system hours in survey
c     daysur         total number of days in survey
c     mcluster       distribution of clusters found by survey
c
      character*1 flag

      do 10 j=0,5
      do 5 k=0,5
      surname(j,k)='blank'
5     continue
10    continue

      open (1,file='survey.in')

      do 100 i=1,10
      read (1,*,err=110) m,j,k
      read (1,*) m,surname(j,k)
      read (1,*) m,pdm(j,k)
      read (1,*) m,pdc(j,k)
      read (1,*) m,fmd(j,k)
      read (1,*) m,fcd(j,k)
      read (1,*) m,al(j,k)
      read (1,*) m,hrlman(j,k)
      read (1,*) m,hrxman(j,k)
      read (1,*) m,dayhr(j,k)
      read (1,*) m,aperhr(j,k)
      read (1,*) m,dcyc(j,k)
      read (1,*)
      write (*,*) i

100   continue

110   continue
      close (1)

      do 200 k=1,2
      if (k.eq.1) n=2
      if (k.eq.2) n=0
      write (n,*)
      write (n,*) '                   survey system inputs'
      write (n,*)

      do 175 l=0,5

      do 170 m=0,5
      if (surname(m,l).eq.'blank') go to 170

      write (n,*) '1   ',m,l,'         primary or supplemental'
      write (n,*) '2   ',surname(m,l)
      write (n,1) '3   ',pdm(m,l),'   probability mine detection'
      write (n,1) '4   ',pdc(m,l),'   probability cluster detection'
      write (n,1) '5   ',fmd(m,l),'   false mine detection per km^2'
      write (n,1) '6   ',fcd(m,l),'   false cluster detection % km^2'
      write (n,1) '7   ',al(m,l),'    maximum location error meters'
      write (n,1) '8   ',hrlman(m,l),'local manhours per km^2 '
      write (n,1) '9   ',hrxman(m,l),'expatriate mnhr per km^2 '
      write (n,1) '10 ',dayhr(m,l),' work day number of hours'
      write (n,1) '11 ',aperhr(m,l),'survey system km^2 per hour'
      write (n,1) '12 ',dcyc(m,l),'  system duty cycle hours per day'
      write (n,1)

1     format (1x,a3,f10.2,a50)

170   continue

175   continue

200   continue

c
c     survey total area with all primary systems
c
      l=0

      do 300 m=1,5
      if (surname(m,l).eq.'blank') go to 300

c     for each cluster, find quantity surveyed
c     inputs are based on either a mine detection or a cluster
c     detection probability.  The one that is not zero is the
c     routine used.

      if (pdm(m,l).eq.0.0) then
c     survey based on cluster detection probability
       do 210 mc=1,5
210    mcluster(m,l,mc)=ncluster(mc)*pdc(m,l)
      else
```

```
c       cluster detection is based on individual mine detection
c       probability
         do 220 mc=1,5
         xmines=cluster(mc,3)
         dpmine=pdm(m,l)
c       probability of detecting cluster is based on the probability
c       of detecting any one mine, so you've got nmines shots with
c       dpmine
        pdno=(1.0-dpmine)**xmines
220     mcluster(m,l,mc)=ncluster(mc)*(1.0-pdno)
        endif

c       find area which must be surveyed due to false alarms.
c       again, this is based either on an individual mine or
c       individual cluster false detection rate
c
        if (fmd(m,l).eq.0.0) then
c       false area is base on false cluster rate
c       of every square kilometer of interest, this percentage
c       will be demined, but may contain no mines
         farea=fcd(m,l)*atotal
        else
c       false area is based on a false mine detection and the
c       location error radius
         farea=fmd(m,l)*atotal*al(m,l)*al(m,l)*3.14159/1000./1000.
        endif

        if (fmd(m,l).eq.0.0.and.fcd(m,l).eq.0.0) then
c       this is a unique situation where the system does not give
c       significant false alarms, but may have a position error
c       on a valid target, which in effect gives false area that
c       must be searched.  MEDDS is a good example of this.  So
c       determine false area based on the total number of clusters
c       in the scenario and the location error area for this system.
c        find total number of clusters
         nctotal=0
         do 230 imc=1,5
230      nctotal=nctotal+mcluster(m,l,imc)
         farea=nctotal*al(m,l)*al(m,l)*3.14159/1000./1000.
        endif

        aunm(m,l)=farea
c
        hrlms(m,l)=hrlman(m,l)*atotal
        hrxms(m,l)=hrxman(m,l)*atotal
        if (aperhr(m,l).ne.0.0.and.dcyc(m,l).ne.0.0) then
         hrsyss(m,l)=atotal/aperhr(m,l)
         daysur(m,l)=hrsyss(m,l)/dcyc(m,l)
        endif

300     continue

c       supplementary survey
c       for each primary system results, resurvey using each
c       supplemental system.
c       the purpose of a supplemental survey is to throw more
c       area away.  However, you may throw mined area away as
c       well.  Obviously, the supplementary system should have
c       a greater probability of detection than the primary system.
c       If this is not your intention, then do a complementary
c       survey.  This means, survey the area not to be cleared
c       and try to find those clusters missed.  But you will also add
c       more erroneous area.  Create a new primary survey system
c       that combines the detection probabilities and false detection
c       probabilities of each into a complementary system.

        do 500 l=1,5
        if (surname(0,l).eq.'blank') go to 500

        do 400 m=1,5
        if (surname(m,0).eq.'blank') go to 400
        surname(m,l)='supplemental'

c       for each cluster, find quantity surveyed
c       inputs are based on either a mine detection or a cluster
c       detection probability.  The one that is not zero is the
c       routine used.

        if (pdm(0,l).eq.0) then
c       survey based on cluster detection probability
         do 310 mc=1,5
310      mcluster(m,l,mc)=mcluster(m,0,mc)*pdc(0,l)
        else
c       cluster detection is based on individual mine detection
c       probability
         do 320 mc=1,5
         xmines=cluster(mc,3)
         dpmine=pdm(0,l)
c       probability of detecting cluster is based on the probability
c       of detecting any one mine, so you've got nmines shots with
c       dpmine
        pdno=(1.0-dpmine)**xmines
320     mcluster(m,l,mc)=mcluster(m,0,mc)*(1.0-pdno)
```

```
      endif

c     find area which must be surveyed due to false alarms.
c     again, this is based either on an individual mine or
c     individual cluster false detection rate
c
      if (fmd(0,l).eq.0.0) then
c     false area is base on false cluster rate
c     of every square kilometer of interest, this percentage
c     will be demined, but may contain no mines
       farea=fcd(0,l)*aunm(m,0)
      else
c     false area is based on a false mine detection and the
c     location error radius
       farea=fmd(0,l)*aunm(m,0)*al(0,l)*al(0,l)*3.14159/1000./1000.
      endif

      if (fmd(0,l).eq.0.0.and.fcd(0,l).eq.0.0) then
c     this is a unique situation where the system does not give
c     significant false alarms, but may have a position error
c     on a valid target, which in effect gives false area that
c     must be searched.  MEDDS is a good example of this.  So
c     determine false area based on the total number of clusters
c     in the scenario and the location error area for this system.
c      find total number of clusters
       nctotal=0
       do 330 imc=1,5
330    nctotal=nctotal+mcluster(m,l,imc)
       farea=nctotal*al(0,l)*al(0,l)*3.14159/1000./1000.
      endif

      aunm(m,l)=farea
c
      hrlms(m,l)=hrlman(0,l)*aunm(m,0)
      hrxms(m,l)=hrxman(0,l)*aunm(m,0)
      if (aperhr(0,l).ne.0.0.and.dcyc(0,l).ne.0.0) then
       hrsyss(m,l)=aunm(m,0)/aperhr(0,l)
       daysur(m,l)=hrsyss(m,l)/dcyc(0,l)
      endif

400   continue

500   continue

c     write survey results


      do 600 k=1,2
      if (k.eq.1) n=2
      if (k.eq.2) n=0
      write (n,*)
      write (n,*) '                survey results'
      write (n,*)

      do 575 l=0,5

      do 570 m=1,5
      if (surname(m,l).eq.'blank') go to 570
      write (n,*) surname(m,l)
      if (surname(m,l).eq.'supplemental') then
       write (n,*) '  primary    ',surname(m,0)
       write (n,*) '  secondary ',surname(0,l)
      endif
      write (n,*) '   distribution of clusters found by survey'
      write (n,*) '   cluster size      number    percent of total'
559   format (i10,5x,i10,f15.2)
      do 560 mc=1,5
      nclus=cluster(mc,3)
      num=mcluster(m,l,mc)
      pfound=num*100./ncluster(mc)
560   write (n,559) nclus,num,pfound
      write (n,*) aunm(m,l),'    unmined area to be cleared km^2'
      write (n,*) hrlms(m,l),'    local manhours'
      write (n,*) hrxms(m,l),'    expatriate manhours'
      write (n,*) hrsyss(m,l),'    system hours'
      write (n,*) daysur(m,l),'    system days'
      write (n,*)

570   continue

575   continue

600   continue

      return
      end


      subroutine clear
c     demining process
      common/outscene/ncluster(5)
      common/inscene/atotal,mtotal,cluster(5,3)
      common/insurvey/surname(6,6),pdm(6,6),pdc(6,6),fmd(6,6),fcd(6,6)
```

```
     & ,al(6,6),hrlman(6,6),hrxman(6,6),dayhr(6,6),aperhr(6,6),dcyc(6,6)
        character*30 surname
        common/outsurvey/aunm(6,6),hrlms(6,6),hrxms(6,6),hrsyss(6,6),
     &  daysur(6,6),mcluster(6,6,5)
        common/indemine/dename(10),nteam(10),tex(10),ntype(10),safe(10),
     &  nsime(10,2),tneut(10),workhr(10),fal(10),pd(10),srate(10)
        character*30 dename
c       dename              demining process name
c       nteam               basic team size number of people
c       tex                 minutes to excavate/verify a target
c       ntype               neutralization type - 1,batch 2,continuous
c       safe                neutralization safe zone area m^2
c       nsime ,1            number of mines per simultaneous neutralization
c             ,2            number of detections sumultaneously excavated
c       tneut               minutes for each neutralization
c       workhr              work day hours
c       fal                 false alarms per 100 m^2
c       pd                  probability of mine detection
c       srate               basic team sweep rate m^2/hr
c
        common/outdemine/nmines(10,6,6),nbatch(10,6,6),teamdays(10,6,6)
c       nmines              number of mines neutralized, per survey
c       nbatch              number of batch neutralizations
c       teamdays            number of team days to clear surveyed area
c
        character*1 flag

        do 5 k=1,10
        dename(k)='blank'
5       continue

        open (1,file='demine.in')

        do 100 i=1,10
        read (1,*,err=110) m,j
        read (1,*) m,dename(j)
        read (1,*) m,nteam(j)
        read (1,*) m,tex(j)
        read (1,*) m,ntype(j)
        read (1,*) m,safe(j)
        read (1,*) m,nsime(j,1)
        read (1,*) m,nsime(j,2)
        read (1,*) m,tneut(j)
        read (1,*) m,workhr(j)
        read (1,*) m,fal(j)
        read (1,*) m,pd(j)
        read (1,*) m,srate(j)
        read (1,*)
        write (*,*) i

100     continue

110     continue
        close (1)

        do 200 k=1,2
        if (k.eq.1) n=2
        if (k.eq.2) n=0
        write (n,*)
        write (n,*) '                 demining process inputs'
        write (n,*)

        do 170 l=1,10

        if (dename(l).eq.'blank') go to 170

        write (n,*) '1  ',l,'           demining process number'
        write (n,*) '2  ',dename(l)
        write (n,2) '3  ',nteam(l),'    basic team size number of people'
        write (n,1) '4  ',tex(l),'      minutes to excavate/verify'
        write (n,2) '5  ',ntype(l),'    1=batch 2=continuous flow'
        write (n,1) '6  ',safe(l),'     neutralization safe zone m^2 '
        write (n,2) '7  ',nsime(l,1),' number of mines per neutral.'
        write (n,2) '8  ',nsime(l,2),' number of simultan. excavat.'
        write (n,1) '9  ',tneut(l),'    minutes for each neutralization'
        write (n,1) '10 ',workhr(l),'   work day hours '
        write (n,1) '11 ',fal(l),'      false alarms per 100 m^2'
        write (n,1) '12 ',pd(l),'       probability of mine detection'
        write (n,1) '13 ',srate(l),'    basic team sweep rate m^2/hr'
        write (n,*)

1       format (1x,a3,f13.2,a40)
2       format (1x,a3,i13,a40)

170     continue

200     continue

c       demine each survey results using each clearance process

        do 1000 k=1,10
        if (dename(k).eq.'blank') go to 1000
```

```
c       cycle through each survey results

        do 950 l=0,5

        do 900 m=1,5
        if (surname(m,l).eq.'blank') go to 950
c
c       clear empty area while accounting for false alarms
c       continuous flow processes must stop and verify each false alarm
c       so slow down process by the time required for each false alarm
         farea=aunm(m,l)*1000.*1000.
         rate=1.0/srate(k)
c        hrs/m^2
        if (ntype(k).eq.2) then
c       continuous flow
         frate=fal(k)/100.
c        FA/m^2
         rlos=frate*(tex(k)/60.0)
c        hrs/m^2
c       effective clearing hours per meter squared
         rate=rate+rlos
c       inverse it:     m^2 /hr
         rate=1.0/rate
        else
c       batch process
c       batch process clears at the slower of either the sweep rate
c       or the rate at which all false alarms can be excavated
c       area of cluster
        aclus=cluster(mc,2)
c       false alarm density in FA/m^2
        false=fal(k)/100.
        tday=workhr(k)
        sum1=false/nsime(k,2)*tex(k)/60.
        area1=tday/sum1
        sum2=1.0/srate(k)
        area2=tday/sum2
         if (area1.lt.area2) dayarea=area1
         if (area2.le.area1) dayarea=area2
c       effective m^2 per day
        rate=dayarea
c       convert to hourly rate
        rate=rate/tday
        endif

c       convert to day rate
        drate=rate*workhr(k)
c       team days to clear empty area

        teamdays(k,m,l)=farea/drate

c       clear clusters
c
        numbatch=0
        daysnum=0
        nummines=0
        do 210 mc=1,5
c       cycle through each cluster type and find time to clear
c       number of each cluster type
        kclus=mcluster(m,l,mc)
c       number of mines in this cluster type
        kmine=cluster(mc,3)
c       area of cluster
        aclus=cluster(mc,2)
c       false alarm density in FA/m^2
        false=fal(k)/100.
c
c       continuous clearing or batch clearing ?
        if (ntype(k).eq.2) then
c       continuous flow
c       subtract neutralization rate from false alarm adjusted rate
c       so slow down process by the time required for each mine
         ratek=kmine/aclus
c        mines/m^2 .
         rlos=ratek*(tneut(k)/60.0)
c        hrs/m^2
         rate=1.0/rate
c        hrs/m^2 (inverse false alarm clearing rate)
         rate=rate+rlos
c        hours to clear this cluster
         hours=aclus*rate
c        days to clear this cluster
         day=hours/workhr(k)
c        days to clear all of these clusters
         days=day+kclus
c        number of batches and mines cleared
         numbatch=numbatch+kmine*kclus
         nummines=nummines+kmine*kclus
        else
c       batch process
c       to reach closure, false alarms and live targets must be
c       excavated and verified in time to destroy all live targets
c       by the end of the day.
c       therefore, find how many detections constitute ending the sweep
```

```
c       day.
c       two conditions:  either sweep rate + neutralization rate
c       or               excavation rate   + neutralizaiton rate
c       dominates.
c       calculate both sweep areas based on the working day
c       and see which is smaller.  That is the area cleared each day
c       per team.
         tday=workhr(k)
         density=real(kmine/aclus)
         nsafe=int(aclus/safe(k))
         if (nsafe.eq.0) nsafe=1
         sum1=(density+false)/nsime(k,2)*tex(k)/60.
         sum1=sum1+density/nsime(k,1)/nsafe*tneut(k)/60.
         area1=tday/sum1
         sum2=1.0/srate(k)+density/nsime(k,1)/nsafe*tneut(k)/60.
         area2=tday/sum2
         if (area1.lt.area2) dayarea=area1
         if (area2.le.area1) dayarea=area2
c       days to clear this cluster
         day=aclus/dayarea
c       days to clear all of these clusters
         days=day*kclus
c       number of batches
         bpclus=kmine/nsime(k,1)
         if (bpclus.le.1.0) nbpclus=1
         if (bpclus.gt.1.0) nbpclus=int(bpclus)+1
         numbatch=numbatch+nbpclus*kclus
         nummines=nummines+kmine*kclus
        endif

        daysnum=daysnum+days
c       numclear based on probability of detection and total number
        numclear=nummines*pd(k)
        if (ntype(k).eq.2) numbatch=numclear
c       continuous flow
        nmines(k,m,l)=numclear
        nbatch(k,m,l)=numbatch
        teamdays(k,m,l)=teamdays(k,m,l)+daysnum

210     continue

900     continue

950     continue

1000    continue

        do 2000 k=1,2
        if (k.eq.1) n=2
        if (k.eq.2) n=0
        write (n,*)
        write (n,*) '               demining process results'
        write (n,*)

        do 1700 l=1,10
        if (dename(l).eq.'blank') go to 1700

        do 1650 m=1,5

        do 1600 j=0,5
        if (surname(m,j).eq.'blank') go to 1600
        write (n,*) ' demining process      ',dename(l)
        write (n,*) ' survey process        ',surname(m,j)
        if (surname(m,j).eq.'supplemental') then
         write (n,*) '  primary          ',surname(m,0)
         write (n,*) '  secondary        ',surname(0,j)
        endif

        write (n,*) nmines(l,m,j),' number of mines neutralized'
c       write (n,*) nbatch(l,m,j),' number of batch neutralizations'
        write (n,1599) teamdays(l,m,j),' number of team days to clear'
        write (n,*)

1599    format (1x,f15.0,a30)

1600    continue

1650    continue

1700    continue

2000    continue

        return
        end


        subroutine costs
c       cost analysis
        common/outscene/ncluster(5)
        common/inscene/atotal,mtotal,cluster(5,3)
        common/insurvey/surname(6,6),pdm(6,6),pdc(6,6),fmd(6,6),fcd(6,6)
```

```
     & ,al(6,6),hrlman(6,6),hrxman(6,6),dayhr(6,6),aperhr(6,6),dcyc(6,6)
       character*30 surname
       common/outsurvey/aunm(6,6),hrlms(6,6),hrxms(6,6),hrsyss(6,6),
     & daysur(6,6),mcluster(6,6,5)
       common/indemine/dename(10),nteam(10),tex(10),ntype(10),safe(10),
     & nsime(10,2),tneut(10),workhr(10),fal(10),pd(10),srate(10)
       character*30 dename
       common/outdemine/nmines(10,6,6),nbatch(10,6,6),teamdays(10,6,6)
c
       common/inc1/scl(6,6),scx(6,6),scsys(6,6),sctr(6,6),sclog(6,6),
     & loesl(6,6),loesx(6,6),loessys(6,6)
c      scl            survey daily cost for local person
c      scx            survey daily cost for expatriate
c      scsys          survey daily cost for system
c      sctr           survey cost to train each person
c      sclog          survey daily logistics cost per man
c      loesl          survey level of effort (# men) local
c      loesx          survey LOE expatriate
c      loessys        survey LOE # of systems
c
       common/inc2/dcl(10),dcx(10),dcsys(10),dctr(10),dclog(10),
     & loed(10),ndx(10),dcexpl(10),dcadd(10)
c      dcexpl         demine explosive neutralization cost per mine
c      dcadd          demine additional cost per batch
c      dcl            demine daily cost for local person
c      dcx            demine daily cost for expatriate
c      dcsys          demine daily cost for system
c      dctr           demine cost to train each person
c      dclog          demine daily logistics cost per man
c      loed           demine level of effort # of basic teams
c      ndx            demine number of expatriates in basic team
c
c
       character*1 flag

       open (1,file='cost1.in')

       do 100 i=1,10
       read (1,*,err=111) m,j,k
       read (1,*) m,surname(j,k)
       read (1,*) m,scl(j,k)
       read (1,*) m,scx(j,k)
       read (1,*) m,scsys(j,k)
       read (1,*) m,sctr(j,k)
       read (1,*) m,sclog(j,k)
       read (1,*) m,loesl(j,k)
       read (1,*) m,loesx(j,k)
       read (1,*) m,loessys(j,k)
       read (1,*)
       write (*,*) i

100    continue
111    continue
       close (1)

       open (1,file='cost2.in')

       do 120 i=1,10
       read (1,*,err=121) m,j
       read (1,*) m,dename(j)
       read (1,*) m,dcexpl(j)
       read (1,*) m,dcadd(j)
       read (1,*) m,dcl(j)
       read (1,*) m,dcx(j)
       read (1,*) m,dcsys(j)
       read (1,*) m,dctr(j)
       read (1,*) m,dclog(j)
       read (1,*) m,loed(j)
       read (1,*) m,ndx(j)
       read (1,*)
       write (*,*) i

120    continue
121    continue
       close (1)

       do 200 k=1,2
       if (k.eq.1) n=2
       if (k.eq.2) n=0
       write (n,*)
       write (n,*) '                 survey system cost inputs'
       write (n,*)

       do 175 l=0,5

       do 170 m=0,5
       if (surname(m,l).eq.'blank') go to 170
       if (surname(m,l).eq.'supplemental') go to 170

       write (n,*) '1  ',m,l,'        primary or supplemental'
       write (n,*) '2  ',surname(m,l)
       write (n,1) '3  ',scl(m,l),'     survey local daily rate'
       write (n,1) '4  ',scx(m,l),'     survey expat daily rate'
```

```
        if (daysur(m,0).eq.0.0) then
c       time based on manpower
         ptime=(dl+dx)/(nl+nx)
        else
c       time based on number of survey systems
         ptime=daysur(m,0)/nsys
        endif

c       sum all costs:
        pcost=cdayl*dl+cdayx*dx+cdaysys*dsys+cdaylog*nl*ptime
        pcost=pcost+ctrain*(nl+nx)

        stime=0.0
        scost=0.0

        if (l.ne.0) then
c       add in supplemental survey time and costs
c       costs:
         cdayl=scl(0,l)
         cdayx=scx(0,l)
         cdaysys=scsys(0,l)
         cdaylog=sclog(0,l)
         ctrain=sctr(0,l)
c       hours:
         hl=hrlms(m,l)
         hx=hrxms(m,l)
         hsys=hrsyss(m,l)
c       convert hours to days:
         dhr=dayhr(0,l)
         dl=hl/dhr
         dx=hx/dhr
         dsys=hsys/dhr
c       levels of effort:
         nl=loesl(0,l)
         nx=loesx(0,l)
         nsys=loessys(0,l)
c       find total supplemental survey time
         if (daysur(m,l).eq.0.0) then
c       time based on manpower
          stime=(dl+dx)/(nl+nx)
         else
c       time based on number of survey systems
          stime=daysur(m,l)/nsys
         endif
c       sum all costs:
        scost=cdayl*dl+cdayx*dx+cdaysys*dsys+cdaylog*nl*stime
        scost=scost+ctrain*(nl+nx)
        endif
c
c       total time and cost of this survey process
        stcost=pcost+scost
c       total time is based on longest time, either primary or
c       supplemental, since they can be run nearly concurrently
        if (ptime.ge.stime) then
         sttime=ptime
        else
         sttime=stime
        endif
c        sttime=ptime+stime
c
c       find total cost of demining this survey, and total time
c
c       costs:
        xpmine=dcexpl(k)
        xpbatch=dcadd(k)
        cdayl=dcl(k)
        cdayx=dcx(k)
        cdaysys=dcsys(k)
        cdaylog=dclog(k)
        ctrain=dctr(k)
c       clearing results:
        nummines=nmines(k,m,l)
        numbatch=nbatch(k,m,l)
c       team days:
        dteam=teamdays(k,m,l)
c       team makeup:
        nxt=ndx(k)
        nlt=nteam(k)-nxt
c       levels of effort:
        nteams=loed(k)
c       sum a team-day cost:
        dcost=cdayl*nlt+cdayx*nxt+cdaysys+cdaylog*nteam(k)
c       based on the number of team days for clearing, find cost of
c       all teams:
        tcost=dteam*dcost
c       sum cost for clearing mines and batches
        cclear=nummines*xpmine+numbatch*xpbatch
c       combine for total clearing costs
        tcost=tcost+cclear
c       find total clearing time based on number of teams
        tclear=dteam/nteams
c
c       output costs and time for area surveyed and cleared
```

```
c
      do 800 kk=1,2
      if (kk.eq.1) kn=2
      if (kk.eq.2) kn=0
      write (kn,*)
      write (kn,*) '        survey and demining process costs'

      write (kn,*) ' demining process      ',dename(k)
      write (kn,*) ' survey process        ',surname(m,l)
      if (surname(m,l).eq.'supplemental') then
       write (kn,*) '  primary      ',surname(m,0)
       write (kn,*) '  secondary    ',surname(0,l)
      endif

      write (kn,799) stcost,' survey process cost (dollars)'
      write (kn,799) sttime,' survey process time (days)'
      if (surname(m,l).eq.'supplemental') then
       write (kn,799) ptime,' primary survey time'
       write (kn,799) stime,' supplemental survey time'
      endif
      write (kn,799) tcost, ' clearance process cost'
      write (kn,799) tclear,' clearance process time'
      write (kn,*)

799   format (1x,f15.0,a40)

800   continue

900   continue

950   continue

1000  continue

      return
      end
```

```
1,1,0
2,'dogs (MEDDS)'
3,0.95
4,0.0
5,0.0
6,0.0
7,125.0
8,0.0
9,40.0
10,8.0
11,0.05
12,8.0
*
1,0,1
2,'airborne (helicopter)'
3,0.70
4,0.0
5,0.5
6,0.0
7,150.0
8,0.0
9,.465
10,8.0
11,4.3
12,8.0
*
*
*
1,1,0
2,'humint'
3,0.0
4,0.95
5,0.0
6,.33
7,0.0
8,30.0
9,0.0
10,8.0
11,0.0
12,0.0
*
*
*
*
*
*
*
*
*
```

primary and supplemental survey system parameters

1. primary survey number, supplemental survey number
2. name type
3. individual mine detection probability
4. cluster detection probability
5. false mine detection rate per km^2
6. false cluster detection rate per km^2
7. location accuracy (maximum error meters)
8. local manhours per km^2 of survey
9. expatriate manhours per km^2 of survey
10. work day (hours)
11. survey system km^2 per hour of survey
12. system duty cycle (hours per day)

```
1,1,0
2,'dogs (MEDDS)'
3,0.0
4,300.
5,160.
6,3000.
7,12.
8,0
9,160
10,40
*
1,0,1
2,'airborne'
3,0.0
4,300.
5,2500.
6,3000.
7,12.
8,0
9,4
10,1
*
*
*
1,1,0
2,'humint'
3,16.
4,300.
5,0.0
6,3000.
7,12.
8,50
9,5
10,0
*
*
*
*
```

cost data input each survey type

1. primary survey number, supplemental survey number
2. name type
3. local personnel daily cost
4. expatriate personnel daily cost
5. each survey system daily cost (assume purchase price=5 year life cycle)
6. training costs per man
7. supporting logistics costs per man-day (hardware/equipment=5 years)
8. survey local personnel level of effort (# men)
9. survey expatriate personnel level of effort (# men)
10. survey system level of effort (# systems)

```
1,1
2,'dogs and probing'
3,25.4
4,3.50
5,16.
6,300.
7,65.0
8,3000.
9,12.
10,79
11,0
*
*
1,1
2,'probing'
3,25.4
4,3.50
5,16.
6,300.
7,1.75
8,3000.
9,12.
10,2072
11,0
*
1,2
2,'detectors'
3,25.4
4,3.50
5,16.
6,300.
7,20.0
8,3000.
9,12.
10,118
11,0
*
1,3
2,'dogs and detectors'
3,25.4
4,3.50
5,16.
6,300.
7,75.0
8,3000.
9,12.
10,26
11,0
*
*
```

cost data input each demining process

1. process number
2. process name
3. explosive neutralization cost per mine (bulk explosives+detcord)
4. additional neutralization cost per batch (electrical blasting cap)
5. local personnel daily cost
6. expatriate personnel daily cost
7. each demining system/team daily cost (purchase price=5 year life cycle)
8. training costs per man
9. supporting logistics costs per man (hardware/equipment=5 years)
10. each demining process level of effort (number of basic teams)
11. number of expatriates in a demining team

```
39350.
1000000
1,5.0,1000.,2.
2,20.,1000.,5.
3,50.,1000.,10.
4,20.,1000.,20.
5,5.0,1000.,30.
```

```
total area of interest km^2
# mines
cluster distribution (five max) i, %, area m^2, # mines
```

```
1,1
2,'dogs and probing'
3,40
4,12.
5,1
6,2500.
7,5
8,3
9,5.25
10,8.
11,3.
12,.95
13,1600.
*
*
1,1
2,'probing'
3,9
4,12.
5,2
6,0.
7,1
8,1
9,5.25
10,8.
11,3.
12,.999
13,6.
*
1,2
2,'detectors'
3,11
4,12.
5,1
6,2500.
7,5
8,2
9,5.25
10,8.
11,3.
12,.92
13,340.
*
1,3
2,'dogs and detectors'
3,26
4,12.
5,1
6,2500.
7,5
8,10
9,5.25
10,8.
11,3.
12,.95
13,1600.
*
*
```

demining process inputs

1. process number
2. process name
3. basic team size (# people)
4. excavate/verify time each target (minutes)
5. neutralization process: 1 = batch, 2 = continuous flow
6. area of neutraliation safe zone (m^2)
7. number of mines simultaneously neutralized
8. number of detections simultaneously excavated
9. time each neutralization (minutes)
10. work day (hours)
11. false alarms per 100 m^2
12. probability of detection
13. basic team sweep rate (zero targets) m^2/hr

cost and effectiveness model
for demining operations

scenario input

total area to be considered km^2	39350.0000000
total estimated number of mines	1000000

estimated mine cluster distribution:

% occur.	area m^2	# mines
5.	1000.	2.
20.	1000.	5.
50.	1000.	10.
20.	1000.	20.
5.	1000.	30.

scenario structure

number of clusters

#	# mines	# mines / 100m^2
25000	2.00	.20
40000	5.00	.50
50000	10.00	1.00
10000	20.00	2.00
1667	30.00	3.00

1
2

survey system inputs

1	1	0	primary or supplemental
2	dogs (MEDDS)		
3	.95		probability mine detection
4	.00		probability cluster detection
5	.00		false mine detection per km^2
6	.00		false cluster detection % km^2
7	125.00		maximum location error meters
8	.00		local manhours per km^2
9	40.00		expatriate mnhr per km^2
10	8.00		work day number of hours
11	.05		survey system km^2 per hour
12	8.00		system duty cycle hours per day

1	0	1	primary or supplemental
2	airborne (helicopter)		
3	.70		probability mine detection
4	.00		probability cluster detection
5	.50		false mine detection per km^2
6	.00		false cluster detection % km^2
7	150.00		maximum location error meters
8	.00		local manhours per km^2
9	.47		expatriate mnhr per km^2
10	8.00		work day number of hours
11	4.30		survey system km^2 per hour
12	8.00		system duty cycle hours per day

survey results

dogs (MEDDS)

distribution of clusters found by survey

cluster size	number	percent of total
2	24937	99.75
5	39999	100.00
10	49999	100.00
20	10000	100.00
30	1667	100.00

6214.5560000	unmined area to be cleared km^2
.0000000	local manhours
1574000.0000000	expatriate manhours
787000.0000000	system hours
98375.0000000	system days

supplemental
primary dogs (MEDDS)
secondary airborne (helicopter)

distribution of clusters found by survey

cluster size	number	percent of total
2	22692	90.77
5	39901	99.75
10	49998	100.00
20	9999	99.99
30	1666	99.94

219.6404000	unmined area to be cleared km^2
.0000000	local manhours
2889.7690000	expatriate manhours
1445.2460000	system hours
180.6557000	system days

1

demining process inputs

1	1	demining process number
2	dogs and probing	
3	40	basic team size number of people
4	12.00	minutes to excavate/verify
5	1	1=batch 2=continuous flow
6	2500.00	neutralization safe zone m^2
7	5	number of mines per neutral.
8	3	number of simultan. excavat.
9	5.25	minutes for each neutralization
10	8.00	work day hours
11	3.00	false alarms per 100 m^2
12	.95	probability of mine detection
13	1600.00	basic team sweep rate m^2/hr

demining process results

demining process dogs and probing
survey process dogs (MEDDS)
949875 number of mines neutralized
1699281. number of team days to clear

demining process dogs and probing
survey process supplemental
primary dogs (MEDDS)
secondary airborne (helicopter)
945087 number of mines neutralized
197388. number of team days to clear

1
2
1

survey system cost inputs

1	1	0	primary or supplemental
2	dogs (MEDDS)		
3	.00		survey local daily rate
4	300.00		survey expat daily rate
5	160.00		survey system daily rate
6	3000.00		total training cost each man
7	12.00		survey daily logistics per man
8	0		local level of effort # men
9	160		expatriate LOE # men
10	40		system LOE # systems

1	0	1	primary or supplemental
2	airborne		
3	.00		survey local daily rate
4	300.00		survey expat daily rate
5	2500.00		survey system daily rate
6	3000.00		total training cost each man
7	12.00		survey daily logistics per man
8	0		local level of effort # men
9	4		expatriate LOE # men
10	1		system LOE # systems

demining process cost inputs

1	1	demining process number
2	dogs and probing	
3	25.40	explosive cost per mine
4	3.50	explosive cost per batch
5	16.00	local daily rate
6	300.00	expatriate daily rate
7	65.00	system daily rate
8	3000.00	total training cost per man
9	12.00	daily logistics cost per man
10	79	level of effort # of basic teams
11	0	number of expatriates in a team

survey and demining process costs
demining process dogs and probing
survey process dogs (MEDDS)

75245000.	survey process cost (dollars)
2459.	survey process time (days)
2038743000.	clearance process cost
21510.	clearance process time

survey and demining process costs
demining process dogs and probing
survey process supplemental
primary dogs (MEDDS)
secondary airborne

75817010.	survey process cost (dollars)
2459.	survey process time (days)
2459.	primary survey time
181.	supplemental survey time
258870100.	clearance process cost
2499.	clearance process time